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Investigation of farmer-led breeding goals and strategies in smallholder dairy farming systems to cope with variation in feed sources and quality

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THE UNIVERSITY
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Declaration

I hereby declare that this thesis and the research findings presented in it are my own work, except where acknowledged. No part of this thesis has been submitted to any other University in application for a higher degree or professional qualification.

Aluna Raphael Chawala

28th February 2020

Dedication

This thesis is dedicated to my family for their endless love, support and encouragement

Psalms 139:14

Abstract

Breeding goals and long term breeding strategies for smallholder dairy farmers in Sub-Saharan Africa (SSA) have not been defined clearly. There is a need for a clear breeding goal that reflects priorities, need and expectations of smallholder farmers, who represent the main farming system. Crossbreeding of *Bos taurus* and *Bos indicus* has been advocated as a way of improving biological efficiency of dairy cows in SSA. However, there is little realised genetic gain among the crossbred dairy animals mainly due to lack of clear breeding goals and long-term breeding strategy beyond the production of the first filial generations (F1s). The overarching aim of this PhD thesis was to investigate breeding goals and strategies of dairy cattle evaluation that can be used as a guide for future dairy cattle breeding programmes in low and medium production environments in Sub-Saharan Africa, using Tanzania as a case study. The key hypothesis of this PhD study was that there is a mismatch between the priorities and preferences of smallholder farmers with regards to animal traits and priorities and policies set centrally by government. In order to address this hypothesis, the following specific objectives were addressed: i) to analyse previous scientific literature on the improvement of animal traits in Sub-Saharan Africa and assess the impact of production systems and breed types on dairy cattle performance; ii) to examine the level of genetic progress that has been achieved in the centrally-run breeding programmes of Mpwapwa cattle in Tanzania; iii) to identify farmer-preferred traits and assess their relative importance in smallholder dairy production systems; and iv) to develop and assess different breeding strategies incorporating smallholder farmer preferred traits.

To address the first objective, a systematic literature review of 64 research studies published between 1980 and 2018 on farmers' and institutional dairy trait preferences was made. Meta-analysis was used to examine the production and reproduction performance of dairy cattle in smallholder and large-scale dairy production systems. Overall, qualitative analysis and meta-analysis of published literature showed a main research

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focus towards fertility traits (age at first calving, calving interval, days open and number of services per conceptions), milk yield and disease resistance or survival traits. Butterfat, protein and workability traits such as temperament were rarely considered. The performance of dairy cattle was higher in large-scale farms and centrally-based breeding stations compared to smallholder dairy farmers. Low performance of dairy cattle in smallholder dairy farms was associated with the use of inferior bulls and poor animal husbandry practices. This study suggested that production systems and genetics play a large role in increased dairy productivity in sub-Saharan Africa. Future dairy research should place a greater emphasis on the interactions between improved feeding, disease control and genetics at a production system level to inform profitable combinations of animal traits.

The second objective was to assess the effectiveness of an actual centrally-based breeding programme in Tanzania, which was set up 40 years ago as a possible nucleus to provide genetic improvement to the smallholder dairy farmers. A total of 1,003 total lactation milk records from 385 cows and 78 sires collected from 1967 to 2012 from Tanzania Livestock Research Institute – Mpwapwa were used to estimate genetic parameters and genetic progress for production and fertility traits in a synthetic dual-purpose breed of cattle. Genetic parameters were estimated using mixed animal models of statistical analyses. Heritability estimates for 305-day milk yield ($h^2 = 0.44 \pm 0.04$) and calving interval (0.10 ± 0.05) were statistically greater than zero ($p < 0.05$) suggesting that these traits could be genetically improved with genetic selection. However, overall negative phenotypic and genetic progress was observed over the past four decades. The key recommendation was that a further understanding of the breeding goal and performance of the breed in a smallholder dairy production system is required for an effective and sustainable genetic improvement programme. Because of the absence of animal performance data in smallholder farms and lack of clear breeding goals, the next step was to identify breeding goals for smallholder dairy farmers in a participatory manner.

Objective 3 was addressed by conducting interviews with stakeholders, including senior research scientist from International Livestock Research Institute (ILRI), livestock and extensions officers from local government authorities, and a choice experiment survey with smallholder dairy farmers in Tanzania to identify farmer-preferred traits and their relative importance. Participation of smallholder dairy farmers was considered as critical in the establishment of breeding goals. The study was conducted through visits to 555 randomly selected dairy farms in the sub-humid Eastern coast and temperate Southern highlands of Tanzania. The choice experiment data were analysed using a conditional logit model. Results showed that from a farmer's viewpoint, the most important dairy traits included high milk yield (emphasis coefficient = 1.43 ± 0.059), good fertility (0.85 ± 0.050), easy temperament (0.76 ± 0.066), low feed requirements (-0.56 ± 0.092) and disease resistance (0.48 ± 0.048). Farmers' trait preferences differed between agro-ecological zones and production systems due to variation of climatic conditions, feed resources and local infrastructure. Adaptability to the local environment was considered as a fundamental trait for selecting dairy cattle across production systems and agro-ecological zones. Farmers were willing to invest in improved dairy cattle showing desired traits at an affordable price (coefficient = -0.001 ± 0.0003). Results from addressing this objective provide evidence for designers of breeding programmes to take consideration of specific farmers' preferred traits. A smallholder farmer index comprising all these traits can be developed based on the relative emphasis placed by the farmers on each trait.

A semi-stochastic simulation was then used to investigate dairy cattle breeding scheme designs for different breeding strategies and to determine genetic progress for the farmer preferred traits in smallholder dairy production systems (Objective 4). Identified animal traits in smallholder dairy production systems from objective 3 were simulated. Three key breeding strategies were investigated. The first breeding strategy assumed genetic improvement through continuous importation of genetically superior exotic dairy bulls to SSA. Importation strategies were considered based on either the smallholder

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farmer index from objective 3 or the index in the country of export, which is most often the case. The second strategy assumed that semen from elite exotic bulls were imported and used only once to produce F1 animals. Thereafter, elite animals were selected from within the F1 population based on the smallholder farmer selection index, to establish a synthetic breed with continuous crossing. Finally, the third strategy was to improve the indigenous population by genetically selecting the best bulls based on the smallholder farmer selection index from within the population. Results from the three breeding strategies showed a positive genetic progress of all breeding goal traits over generations. Increase in proportion of cows bred by improved sires through artificial insemination (AI) resulted in a greater genetic response for all selection scenarios. Three mating schemes of 100%, 50% and 30% AI uptake were investigated to quantify the genetic gain of animal traits and selection indexes. All scenarios showed that the importation breeding strategy led to an overall higher genetic progress compared to synthetic breed and within indigenous breed selection strategies, probably due to the high relative emphasis on milk yield by the smallholder farmers. For example, after 15 generations of selection, the genetic response of the importation strategy regarding the farmer index exceeded the corresponding genetic response of the synthetic breed strategy by 20.26%, 51.41% and 65.55% for the three AI schemes, receptively. The former also exceeded the genetic response of the indigenous breed strategy by 43.06%, 64.89% and 75.02% for the three AI schemes, receptively. Our simulation studies have demonstrated the value of including farmer preferred traits in genetic selection of imported genetic material compared to selection based on the circumstances of the exporting country. After 15 generations of selection, the genetic gains from continuous importation of animals based on farmer preferred traits were 8.31% - 9.83% higher compared to importing based on circumstances of the exporting country. Potentially there is an opportunity for breeders to choose an appropriate breeding strategy that fits a particular production environment.

In summary, participatory breeding goals for smallholder dairy farmers in Tanzania were identified and documented. The amount of emphasis for identified breeding goal traits was quantified. Furthermore, appropriate breeding strategies were developed and the genetic progress for each individual trait in a particular breeding strategy was quantified. These findings contribute to the body of knowledge on breeding and genetics in smallholder dairy production systems in SSA. Results from this thesis can be used by farmers, government and other development partners in planning sustainable breeding programmes in Tanzania and Sub-Saharan Africa at large.

Lay Summary

The key decisions with regards to livestock breeding scheme designs in many countries in sub-Saharan Africa tend to be either government- or project-driven, often being short-term, with a focus on upgrading local breeds. As a result, most prior attempts to establish breeding programmes have collapsed due to disrupted funding and changing policies. The mismatch between animal traits that farmers consider valuable and appropriate in the respective production environment, and government policies and priorities may lead to inefficient use of resources and comprise genetic progress or gain. The aim of this PhD study was to combine socioeconomic sciences and animal genetics to develop a clear understanding of farmer's priorities with regards to dairy traits of interest, and examine relevant feasible breeding strategies for dairy cattle improvement. The specific objectives were to: i) analyse previous scientific literature on the improvement of animal traits in Sub-Saharan Africa and assess the impact of production systems and breed types on dairy cattle performance; ii) examine the level of genetic progress that has been achieved in the centrally-run breeding programmes of Mpwapwa cattle in Tanzania; iii) identify farmer preferred traits and assess their relative importance in smallholder dairy production systems; and iv) develop and assess different breeding strategies incorporating smallholder farmer preferred traits.

A critical review and analysis of the scientific literature (objective 1) showed a bias towards the study of the following traits, in order of importance; calving interval, milk yield, age at first calving, lactation length, disease resistance, days open, number of services per conception, growth rate, body conformation score, age at first service, milk solids (% fat and protein) and temperament. Overall, the findings showed a strong bias towards production and fertility traits compared to conformation and welfare traits. Among the production traits, milk butter fat and protein were the least studied traits mainly due to payment system which is based on milk volume. On the other hand, the performance among breed types kept by farmers for dairy production were mainly influenced by production system and breed type.

Lay Summary

The use of improved dairy cattle from nucleus herds as source of improved genetic material in smallholder dairy farms has led to some genetic improvement in terms of increased milk yield and improved fertility compared to indigenous breeds. In objective 2, we examined the level of genetic progress that has been achieved in a centrally-based breeding programme for a period of 40 years. There has been an overall decline in phenotypic and genetic performance regarding production and fertility traits over the past four decades. The conclusion was that, a systematic planning of the genetic improvement programme of the breeding scheme is essential to avoid a declining genetic trend for production and reproduction traits. A favourable trend could be established in this programme and be transferred to smallholder dairy production systems.

Objective 3 aimed to develop a breeding goal and selection criteria of dairy cattle which will be used as a guide for future dairy cattle genetic improvement strategies in smallholder dairy farms. This objective was addressed by conducting interviews with stakeholders, which included senior research scientist from International Livestock Research Institute (ILRI), livestock and extensions officers from local government authorities, and a choice experiment survey with 555 smallholder dairy farmers in Tanzania. In order of perceived priority, farmer-preferred traits included high milk yield, good fertility, easy temperament, low feed requirement and disease resistance. There was a significant difference in farmer's priority traits in different agro-ecological zones and production systems (extensive vs intensive). The identified list of animal traits provided a broader context of a breeding goal based on farmers' viewpoint.

Finally, three breeding strategies were simulated in order to assess expected genetic progress in the farmers' preferred traits. The first breeding strategy portrayed genetic improvement through continuous importation of genetically superior exotic dairy bulls from temperate countries to SSA. After 15 generations of selection, the genetic gains from continuous importation were 20% - 65% higher compared to importing once and then developing a

synthetic breed and 43% - 75% higher than performing genetic selection within the indigenous population. Our simulation studies demonstrated the value of including the SSA farmer-preferred traits in genetic selection of imported genetic material compared to selection based on the circumstances of the exporting country. The benefit of the importation strategy lies on high relative emphasis for milk yield that farmer put on compared to other traits. These findings suggest that there is an opportunity for breeders to take advantage of the simulated selection decisions and breeding strategies.

In conclusion, the present study contributes to current efforts of improving dairy productivity and profitability in smallholder dairy farms, and to defining appropriate dairy cattle breeding goals and strategies for smallholder dairy farmers in Sub-Saharan Africa. Overall, the findings suggest that selection decisions and breeding strategies developed based on farmer's priority traits will increase productivity of dairy animals in Sub-Saharan Africa. These findings can be used as a guide by farmers, government and other development partners in establishing genetic improvement strategies for the prevailing smallholder dairy production systems in Sub-Saharan Africa.

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List of Abbreviations

%	Percent
β_h	β - Coefficients of heterosis
β_r	β - Coefficients of recombination loss
σ^2_a	Additive genetic variance
ADGG	African Dairy Genetic Gains Programme
AHDB	Agriculture & Horticulture Development Board
AI	Artificial insemination
BWT	Mature live-weight
CI	Calving interval
DGEA	Dairy Genetics East Africa Project
EBVs	Estimated Breeding Values
ENVs	Environmental values
F1, F2 and F3	First, second and third filial generation, respectively
G	Genetic variance-covariance matrices
h^2	Heritability
ILRI	International Livestock Research Institute
Kg	Kilogramme
L	Litres
LF	Lifespan
LMY	Lactation milk yield
MVN	Multivariate normal distributions
NR56	Non-return at 56 days
PD	Proportion of exotic genes for the dam

List of Abbreviations

PS	Proportion of exotic genes for the sire
Rec	Recombination loss
SCC	Somatic cell count
SRUC	Scotland's Rural College
SSA	Sub-Saharan Africa
TBV	True breeding value
TEMP	Temperament
UK	United Kingdom
URT	United Republic of Tanzania

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Publications and Conference Contributions

Journal articles (peer reviewed)

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- 2 Chawala, A. R., Banos, G., Peters, A., & Chagunda, M. G. G. (2019). Farmer-preferred traits in smallholder dairy farming systems in Tanzania. *Tropical Animal Health and Production*, 51(6), 1337–1344.
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Chapter 1 General Introduction

1.1 Importance of dairy production in Sub-Saharan Africa

World milk production is estimated at 843 million tonnes per year (FAO 2019) with an average annual growth rate of 2.1% (OECD/FAO 2018). Sub-Saharan Africa (SSA) countries have demonstrated a higher annual growth rate in milk production of 2.5% (OECD/FAO 2016). Nevertheless, production is not sufficient to meet consumption needs and imports of milk to Africa account for 15% of total imports, second only to Asia (FAO 2017). Dairy production is an important sector in SSA, with high potential for improving the food security, poverty reduction and employment creation (Chagunda et al. 2015; FAO, GDP and IFCN 2018). The dairy sector in SSA is considered a source of employment, as it absorbs large under-employed rural labour. It is estimated that, for every 1,000 litres of milk produced, 50 farm jobs are created (Smallholder Dairy Project 2005). In addition, studies have indicated an increase of the dairy product consumption in Sub-Saharan Africa. For example, the estimates suggest that imports of dairy products in East Africa countries have almost doubled from 165,400 tonnes in 2000 to 325,200 tonnes in 2011 (FAO 2014). The increase in imports of dairy products shows that there is a widening gap between domestic production and consumption (FAO 2017). The increasing demand of milk and milk products is associated with rapid population growth, urbanisation and increase in per capita income.

The dairy sector in SSA is divided into traditional, smallholder and large-scale production systems. The traditional system can be further divided into pastoral and agro-pastoral farming systems and accounts for more than 90% of the cattle population which are mainly found in arid and semi-arid areas of SSA. Cattle under traditional systems belong to the *Bos indicus* species and have low milk production potential but are well adapted to the tropical conditions (Ndambi et al. 2007; Tadesse and Dessie 2003). Under this production system, the average herd size is approximately 135 cattle and animals are dual purpose for milk and meat production.

The smallholder dairy farming system is common in rural and peri-urban with some degree of intensification by a combination of grazing, cut and carry, and concentrate-feeding with milk production as their main objective. Here, there is use of *Bos taurus* (*exotics*) and crossbred cows mainly of *Bos taurus* and *Bos indicus* (*Zebu*). The farms here are small (1-2 ha) with an average herd size of 1 – 5 cows. It is estimated that 60 to 90 percent of milk in formal marketing channels is produced in smallholder farming systems. Large-scale production systems involve farms with 50 or more dairy cattle that are usually owned by government, cooperatives and private farmers (Njombe et al. 2011). Smallholder and large-scale farming are predominantly market-oriented production systems and in recent decades, have rapidly developed in rural, urban and peri-urban areas mainly due to expanding market demand (Ndambi et al. 2007). However, large-scale dairy farming in SSA does not account for a large share of national milk production (Chagunda et al. 2015).

Figure 1.1 gives an example of the performance of dairy cattle in smallholder and large-scale farms in SSA. There is a considerable milk yield gap between smallholder and large-scale farms. Overall, lowest yield of an average of 5L/cow/day is realised in majority (>90%) of the smallholder dairy farms (DGEA 2015; Ojango et al. 2017). Highest yield is achieved under large-scale and very few (<5%) best smallholder dairy farms as illustrated in Figure 1.1.

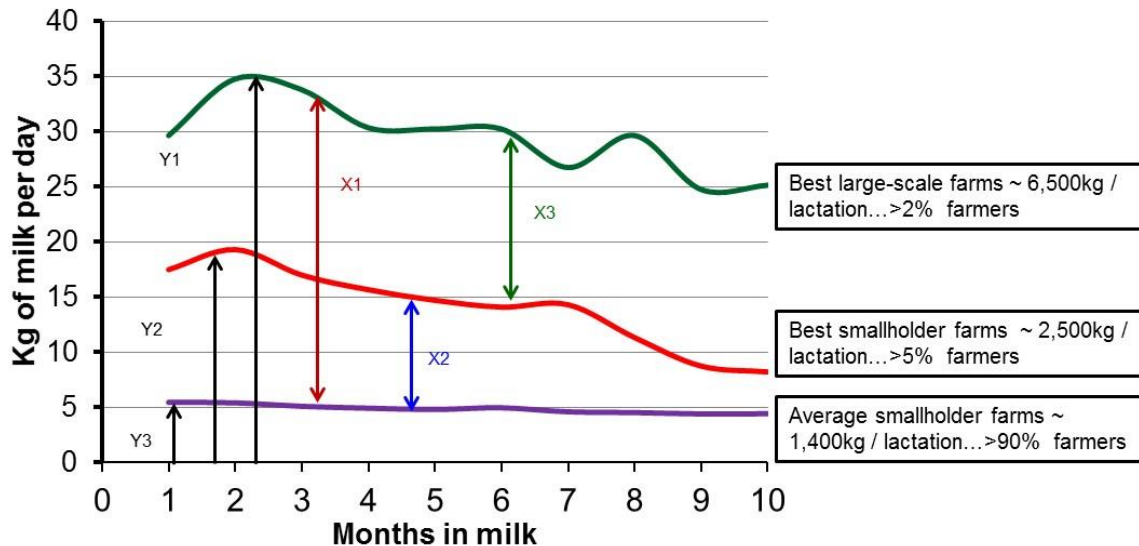


Figure 1.1 Lactation curves of dairy cattle demonstrating yield gaps (X_1 , X_2 , and X_3) in milk production by dairy cattle under smallholder and large-scale farming systems. **Source:** DGEA, 2015 and Ojango et al. 2017.

Although dairy production in SSA is practiced in many countries under the systems described above, the PhD thesis from this point onwards focuses on smallholder dairy farming system in Tanzania, and considers it as case study. Smallholder dairy systems in Tanzania are generally similar to other countries in Eastern and Southern Africa such as Kenya, Uganda, Rwanda, Ethiopia, Zambia and Malawi.

1.2 Dairy cattle breeding initiatives to increase productivity levels in Tanzania

The existing literature shows that the breeding activities aimed at improving milk production in Tanzania were initiated in 1920s (Syrtstad 1990) and were intensified in the 1960s and 1970s aiming at establishing large-scale dairy farms through direct importation of *Bos taurus* breeds from temperate countries (Kurwijila & Boki 2003). Nevertheless, direct introduction of exotic breed from temperate countries faced a number of challenges including lack of adaptability to tropical climate and resistance to diseases and parasites

(Njombe et al. 2011; Swai et al. 2010). Since the mid-1960s efforts of increasing milk production were shifted to crossbreeding exotic breeds with the Tanganyika Shorthorn Zebu (TSHZ), aiming at upgrading the latter. To increase the supply of dairy heifers to smallholder dairy farmers, efforts were also made during this time to produce F1 heifers in livestock multiplication farms /units and these heifers were sold to smallholder dairy farmers or to non-governmental organisations, which, in turn, distributed them to smallholder farmers (Chenyambuga and Mseleko 2009). Crossbreeding of zebu cows with exotic dairy breeds raised the potential milk production of zebu cows from 530 – 950kg (Kurwijila & Boki 2003) to 1,260 – 2,646 kg of milk per lactation (Chenyambuga & Mseleko 2009., Msanga et al. 2000).

The government for a long time has been responsible for increasing productivity of dairy cattle through investments in Artificial insemination (AI) infrastructure and equipment. During the early 1980s, the National AI Centre (NAIC) was established in the Arusha region for semen collection and processing. The government of Tanzania has taken various initiative to strength the NAIC to become the main source for improved semen across the country. Moreover, incentives were offered to smallholder farmers to use improved semen in their herds. However, the use of AI for crossbreeding to increase the productivity of indigenous cattle has remained low (Katjiuongua and Nelgen 2014). Figure 1.2 shows the trend of semen distribution by breed type from year 2000 to 2016. Overall, semen distribution has gradually increased over years. Inflow of genetics to smallholder dairy farmers has been towards high yielding exotics breeds such as Holstein-Friesian, Ayrshire and Jersey. Although genetic improvement efforts are continuing, the Tanzanian dairy industry is still young with the dairy herd accounting for 3% (783,000 animals) of the total population of 21.28 million cattle in the country (Michael et al. 2018; United Republic of Tanzania (URT) 2006; 2013; 2019). Dairy farming in Tanzania is dominant in the Northern and Southern highlands, and sub-humid coastal and lake zones. According to Michael et al. (2018) the

concentration of improved or high grade dairy cattle in the highlands is more than twice (375,337) compared to coastal and lake zones (156,857).

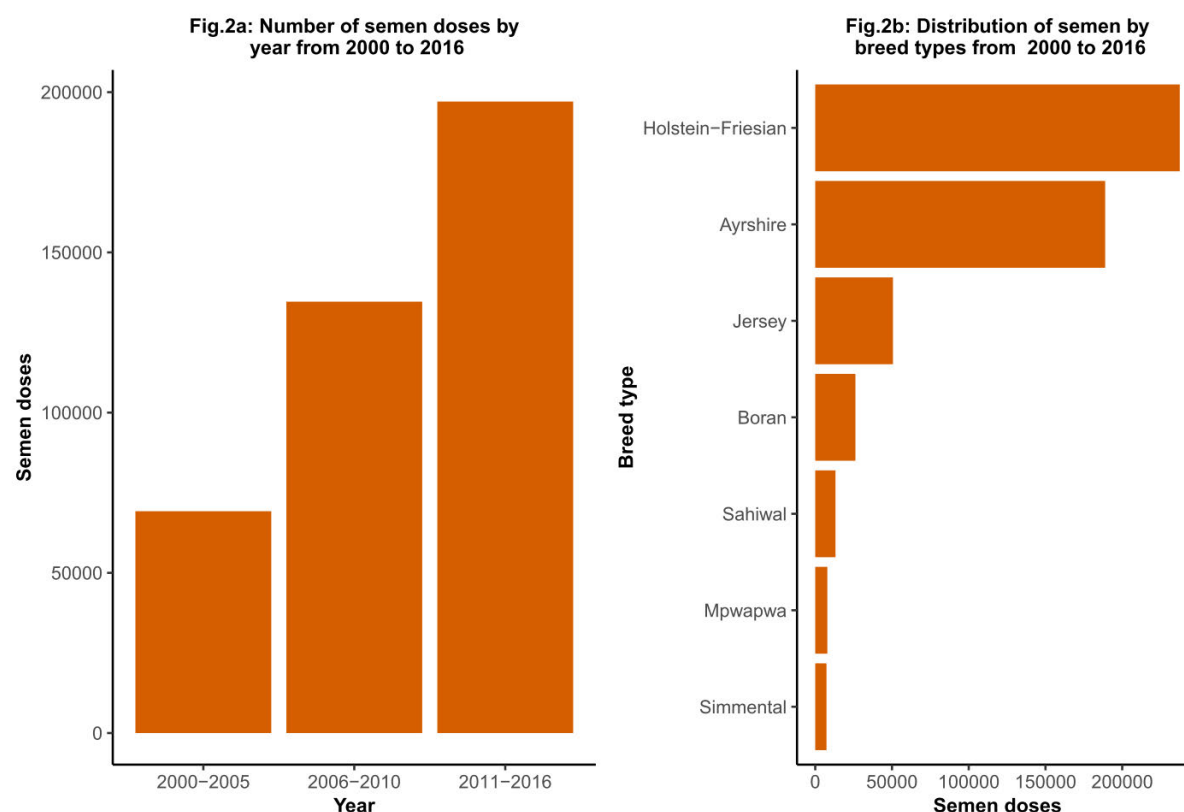


Figure 1.2 Trend of semen distribution by year (2a) and breed type (2b).
Source: Annual reports data from National Artificial Insemination Centre, Arusha, Tanzania

There is a high variation in AI utilisation due to differences in agro-ecological zones, cattle breed and AI infrastructure. Overall, AI adoption is still low due to lack of genetic strategy and necessary infrastructure for extensive AI schemes. Figure 1.3 shows geographic regions with high and low AI adoption in Tanzania. AI is mainly concentrated in Northern highland regions (Arusha and Kilimanjaro) due to their closeness to NAIC followed by the coastal regions of Tanga and Pwani (Swai et al. 2014). Low utilisation of semen in dairy areas of southern highlands (Iringa and Njombe) and lake zone (Kagera) has been associated with low investment in AI infrastructure in the respective areas. AI utilisation is lower in arid and semi-arid areas of northern, central and western Tanzania, particularly in Shinyanga, Tabora, Manyara,

Rukwa and the Maasai area of South of Arusha. A recent study by Mwanga et al. (2019) indicated that AI uptake by smallholder dairy farmers' decrease with increasing distance from the NAIC.

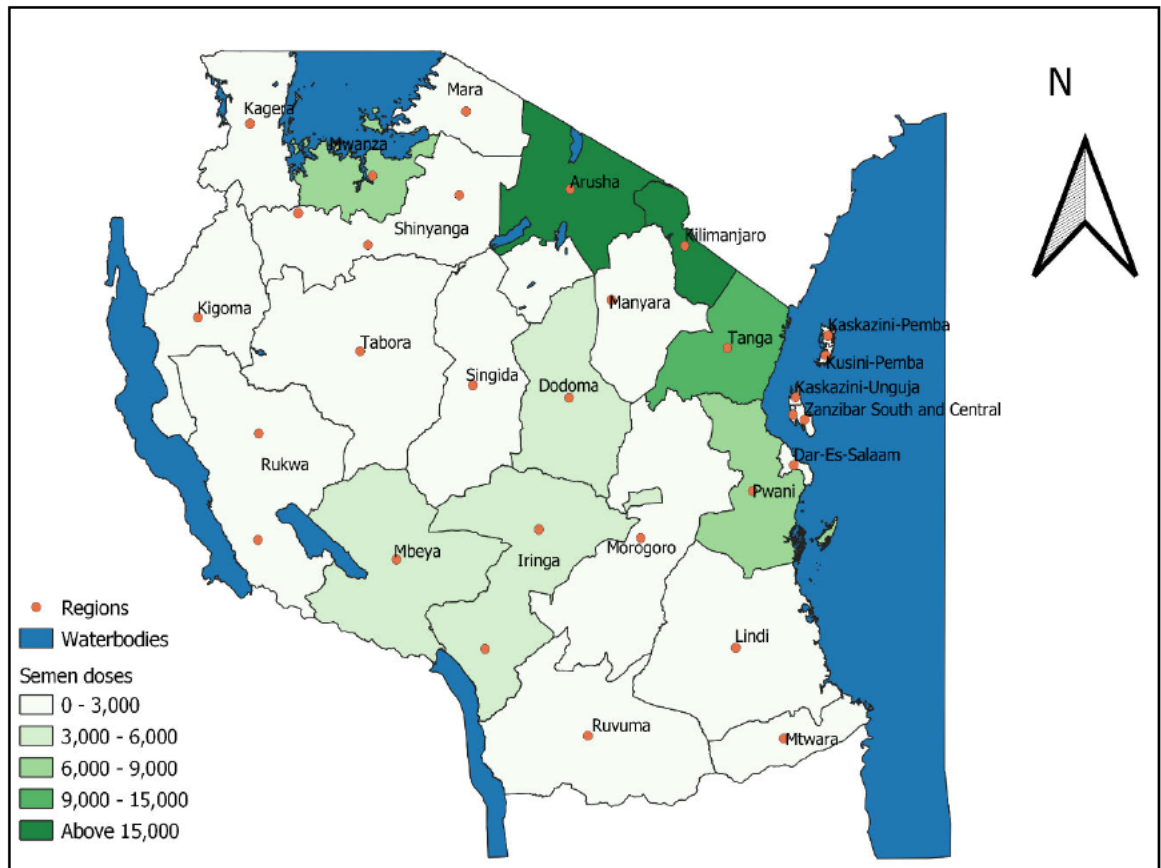


Figure 1.3 AI uptake in different regions of Tanzania based on quantity of semen distribution between year 2012 and 2016. *Source: Created based on annual reports data from National Artificial Insemination Centre, Arusha, Tanzania*

1.3 Milk production trends and consumption gaps in Tanzania

The improved breeds, mainly crossbred between Tanganyika Shorthorn Zebu and exotic dairy breeds, account for about 30% of the 2.5 billion litres of milk produced in the country and 70% of the milk marketed (URT, 2015). It has been documented that the improvement of milk supply in Tanzania has been due to growth in cattle population rather than increase in productivity (Kurwijila & Boki 2003). The current increase in milk production

based on growth of number of cattle rather than productivity per cow is a reflection of inefficient systems in which milk is produced. Dairy imports add another 2 - 3% to the total milk consumption (Nell et al. 2014). Figure 1.4 illustrates the prediction of national consumption and production gap for the near future. With no intervention and investment, the national production-consumption gap is expected to increase up to nearly 6 million litres of milk by 2031. The Tanzania Livestock Master Plan document has highlighted that the widening of this gap can be closed through genetic improvement (breeding), improved feed and health management, value addition of dairy products, and new policies and strategies.

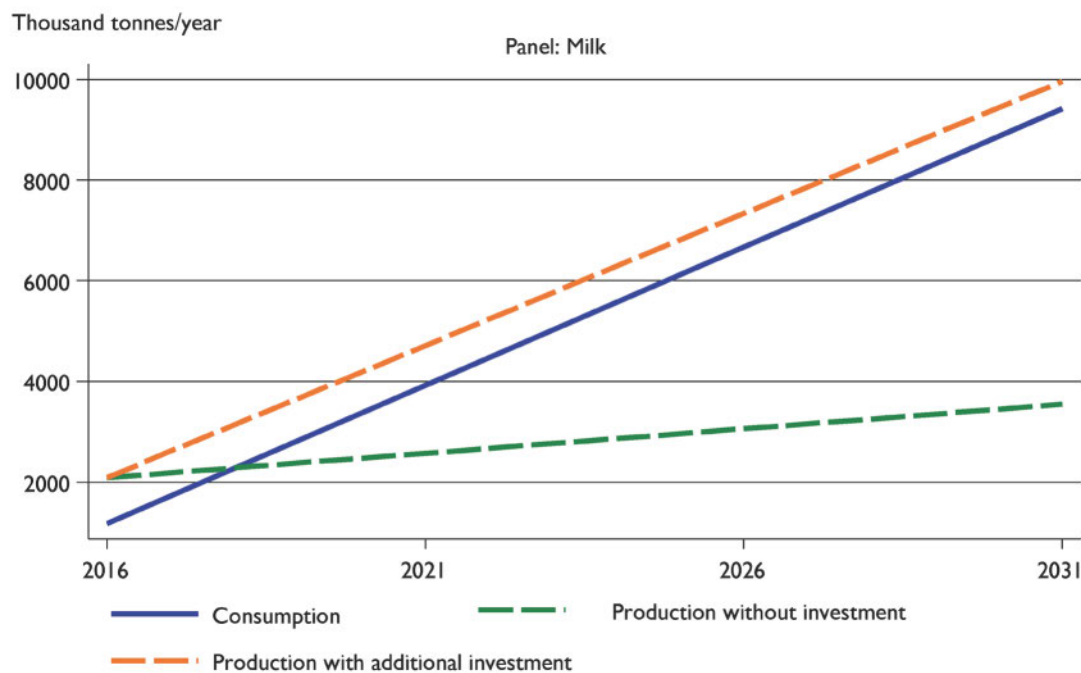


Figure 1.4 Predicted production-consumption balance for cow milk with and without additional investment in Tanzania for 2016 – 2031. *Source: Michael et al. 2018*

1.4 Effect of seasonality on milk production, feed sources and feed quality

Milk production in Tanzania is highly sensitive to local weather, feed availability and milk marketing (Kivaria et al 2006; Mdoe and Wiggins 1996).

There is a considerable variation in milk production in wet and dry seasons. Rainfall availability has an effect on feed availability and hence causes fluctuation in milk production and prices across seasons. Wassena et al. (2015) reported an increase in milk yield during the rainy season due to feed and water availability for intensive and extensive systems. On the other hand, milk production was low in dry season, especially in extensive systems due to shortage of water and decline in quantity and quality of feeds. Milk price is highly dependent on rainfall patterns. Lower milk price has been found in rainy season when milk is plenty and higher prices in dry season when the milk production is limited (Nell et al. 2014).

Smallholder dairy farmers rely on pasture, crop residues and oil seed by-products as major feed sources. However, the quantity and quality of feeds fluctuates across seasons (Lukuyu et al. 2011; Maleko et al. 2018). Fodder scarcity in dry season is considered as a primary constraint for milk production. Conversely, fodder quality is considered as a secondary in terms of importance. It is estimated that milk production may decrease up to 40% in dry season due to variations in fodder quantity and quality (Maleko et al. 2018). The average farm sizes for smallholder dairy farms are small ranging from 1.4 to 3 ha. Lands sizes devoted for pasture production is relatively smaller compared to the land devoted to other food crops and vegetables. Because of their small size, the quantity of feeds produced in these plots cannot meet animal requirements, particularly in dry season. Additionally, the adoption of feed conservation among smallholder dairy farmers is poor (Maleko et al. 2018).

Crop residues from smallholder farms have been adopted as energy and protein source of dairy cattle in dry season. Common crop residues include maize and sorghum stover and rice and bean straws. However, their use in dry season is constrained by poor quality due to low nitrogen and high lignocellulose contents. Likewise, utilisation of grains as animal feed is constrained by high demand for human consumption. For example, maize is Tanzania's staple food and is critical to food security and therefore limiting it

as an alternative source of animal feeds. Grains by products such as maize bran and rice polishing as energy source for dairy cattle is not adequately available (Lukuyu et al 2011, Maleko et al. 2016).

At present, the dairy sector is changing to higher productivity through investments in improved genetics, health, feed and marketing. The key focus is on smallholder dairy farmers (Michael et al. 2018). However, there is scant evidence of relevant research with outcomes suitable for smallholder dairy farming in different agro-ecological zones. Previous studies conducted in Tanzania did not establish animal traits that influence the choice of dairy cattle by farmers. Moreover, there is no clear breeding strategy to aid farmers in the use of available genotypes for improvement (Mujibi et al. 2019). Therefore, the study was undertaken to establish preferences for dairy traits and possible genetic improvement strategies for smallholder dairy farmers in Tanzania. The study emphasises on the need for identifying and ranking dairy cattle based on selection criteria set by farmers. The outputs of the study will lead to the establishment of appropriate breeding goals for different production environments and formulation of sound animal breeding strategies.

This PhD thesis set out to address the following hypotheses;

- i. Previous research studies on cattle performance in SSA have primarily reflected institutional and scientific interests and not addressed all animal traits that are important to smallholder farmers.
- ii. Centrally-driven top-down breeding programmes are predisposed to lack of long-term genetic progress
- iii. Participation of smallholder farmers in the design of bottom-up breeding programmes is feasible.

1.5 Objectives and thesis outline

1.5.1 Objectives

To address these hypotheses the following objectives were set:

- i. To analyse previous scientific literature on the improvement of animal traits in Sub-Saharan Africa and assess the impact of production systems and breed types on dairy cattle performance.
- ii. To examine the level of genetic progress that has been achieved in the centrally-run breeding programmes of Mpwapwa cattle in Tanzania.
- iii. To identify farmer preferred traits and assess their relative importance in smallholder dairy production systems.
- iv. To develop and assess different breeding strategies incorporating smallholder farmer preferred traits.

1.5.2 Thesis outline

This thesis is organised into six chapters, including this introductory chapter (**Chapter 1**). **Chapter 2** reviews the literature concerning the breeding objectives and the impact of production systems and breed types on dairy cattle performance in SSA. **Chapter 3** documents breeding goals and strategies and the level of genetic progress that has been achieved in a centrally-run breeding programme. **Chapter 4** presents the results of the identified farmer-preferred dairy traits and their relative importance using discrete choice experiment survey. **Chapter 5** develops different dairy cattle breeding scheme designs for breeding strategies and examines at predicted genetic progress achieved for the farmer preferred traits from Chapter 4. Finally, **Chapter 6** provides an overall discussion and implication of the findings and future outlook.

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**Chapter 2 Towards a better understanding of
breeding objectives and production
performance of dairy cattle in Sub-
Saharan Africa: A systematic review
and meta-analysis**

2.1 Chapter introduction

In recent years, there have been considerable efforts to increase dairy productivity in Sub-Saharan Africa. However, the major constraint in dairy production at present is lack of specific knowledge on the appropriate breeding goals for different production and management systems. This chapter address the first objective of the thesis. The chapter provide a synthesis, in form of literature review and meta-analysis that could contribute to the formulation of appropriate breeding goals. The key research question for this chapter was “*which traits have featured prominently in previous and current literature with regard to breeding goals for low and medium production environments?*” The study was carried out through a critical review of the literature and a meta-analysis of animal performance records extracted from scientific publications mainly those available in the International Livestock Research Institute (ILRI) and National Agricultural Research Institutes. These included reports, grey literature and peer reviewed scientific publications. The meta-analysis helped to quantify the importance exerted on these traits in the production system. Information was retrieved from electronic databases of DiscoverEd, Google Scholar, CAB Abstracts and International Livestock Research Institute (ILRI) Website (<https://www.ilri.org/>). The Chapter in hereby presented in form of a scientific manuscript that has been accepted for publication in CABI Reviews Journal as:

Chawala, A. R., Mwai, A. O., Peters, A., Banos, G., & Chagunda, M. G. G. (2020). Towards a better understanding of breeding objectives and production performance of dairy cattle in Sub-Saharan Africa: A systematic review and meta-analysis. CABI Reviews. <http://www.cabi.org/cabreviews>. [https:// doi: 10.1079/PAVSNNR202015007](https://doi.org/10.1079/PAVSNNR202015007). (*In press*)

The PhD candidate conducted all the work related to this chapter including formulation of the research question, literature search and selection of studies, data extraction, data analysis, and manuscript writing. This work was conducted under guidance from the supervisors and in collaboration with the remaining authors of the manuscript.

2.2 Manuscript

Towards a better understanding of breeding objectives and production performance of dairy cattle in Sub-Saharan Africa: A systematic review and meta-analysis

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Abstract

The aim of this study was to examine breeding objectives and the impact of production systems and breed types on dairy cattle performance in Sub-Saharan Africa (SSA). A total of 64 research studies published between 1980 and 2018 were used for qualitative analysis (qualitative synthesis) of farmers', scientists and institutional dairy trait preferences. Meta-analysis was conducted to examine the production and reproduction performance of dairy cattle in smallholder and large-scale dairy production systems. Most data used were from smallholder farmers (60%), with the remainder from large-scale farms. Linear mixed-effect models were used to estimate marginal means of production and reproduction traits for different breed types in both production systems. Overall, the results showed that there was a higher emphasis on breeding for improved fertility, increased milk yield and disease resistance. Milk content (fat and protein percentages), temperament, body conformation and total milk cell count (a mastitis indicator) were rarely mentioned in published literature, mainly because of milk pricing policies being volume based. Frequency and multivariate analyses (cluster data analysis) for desirable animal traits suggested that multiple breeding objectives are needed, based on the perceived goals of different farmers and institutions towards genetic improvement for production, reproduction, disease resistance, functional and animal welfare traits. Regardless of breed type, commercial large-scale farms had a higher milk yield ($2,857.0 \pm 233.3$) compared with smallholder dairy farms ($2,419.8 \pm 617.39$). Estimated marginal means for lactation milk yield of the three breed types; Holstein-Friesian, non-Holstein-Friesian dairy breeds (Jersey, Guernsey, Red Dane, Brown Swiss and Ayrshire) and crossbreds (*Bos taurus* x *Bos indicus*) were $3,148.5 \pm 433.00$, $2,995.6 \pm 456.36$ and $1,771.1 \pm 328.52$, respectively. Significantly shorter age at first calving and shorter calving intervals were observed in large-scale farms in comparison to smallholder farms ($p < 0.05$). No significant differences were noted for age at first calving, calving interval, days open and number of services per conception between the breed types. In conclusion, the present

Chapter 2: Review of breeding goals and dairy cattle performance

study suggests that (i) improvement of dairy cattle has focused on reproduction, production and disease resistance traits, reflecting the breeding objectives of farmers, scientists and institutions involved in dairy production, (ii) genetics plays a large role in increased dairy productivity in SSA and (iii) future dairy research should emphasise on the interactions between improved feeding, disease control and genetics at a production level to inform profitable combinations of dairy traits.

Key words:

Trait preference; Breed types; Production systems; Crossbreeding

Introduction

Since the industrial revolution in the late 18th Century, genetic selection for economically important traits in dairy cattle has intensified in Europe, North America, Australia and New Zealand (Eagleton & Monolopoulou, 1981; Montgomerie, 2004; Wiggans, 1991). To enhance dairy productivity, breeding programmes were designed based on farmers' trait preferences (Martin-Collado et al., 2015; Oltenacu & Algers, 2005; Slagboom et al., 2017). This is contrary to the African continent, where natural selection of indigenous and crossbred populations has played the primary role in selecting the fittest animals to survive under challenging tropical environments. Selection for high milk yield in indigenous breeds has rarely been successfully undertaken; instead, the preference has been for the “easier” route of crossbreeding indigenous breeds with exotic breeds to improve milk yield (Galukande et al., 2013; Syrstad, 1990).

Currently, farmers in Sub-Saharan Africa are focusing on higher yielding dairy cattle due to the increasing demand for dairy products. Factors influencing milk consumption include growth in the human population, social infrastructure development and government livestock policies (Bebe, Udo, & Thorpe, 2002; Ojango et al., 2017; Ojango, Wasike, Enahoro, & Okeyo, 2016). Olesen et al., (2000) highlighted the advantages of considering the biological, ecological and social aspects in designing comprehensive animal breeding objectives. They suggest that objectives should target future anticipated production system characteristics in terms of both animal and market requirements and should address both short and long-term needs and prospects. Before making a final decision on any breeding objective, many questions relating to production systems, breeds, breeding infrastructure, socio-economic and cultural values, need to be answered (Berry, 2015; Klopčič, Reents, Philipson, & Kuipers, 2009; Lopez-Villalobos & Garrick, 2005).

Chapter 2: Review of breeding goals and dairy cattle performance

With regards to livestock breeding scheme design, the key decisions in many sub-Saharan Africa countries tend to be made by government or are project driven. These decisions are often short-term with a focus on upgrading the local breeds (Mihret et al., 2017). Existing literature indicates that crossbreeding of *Bos taurus* and *Bos indicus* has been advocated as a way of improving the biological efficiency of dairy cows in sub-Saharan Africa. However, there is little realised genetic gain among the crossbred dairy animals mainly due to a lack of clear breeding goals, selection decisions, supportive infrastructure, policies, and long-term strategy beyond the production of the first filial generations (F1s). Farmer trait preferences are often ignored (Amimo et al., 2007; Chawala et al., 2017; Effa et al., 2011). Philipsson et al., (2011) highlighted that no sustainable breeding programme can be implemented without farmer, policy and financial support. Animal breeders and technical institutions have often failed to translate farmers' preferences into the breeding objectives and selection criteria with appropriate weighting. This has led to limited selection ability for the animals best suited to a particular production environment (French et al., 2001; Swai et al., 2005).

Most genetic improvement programmes involving smallholder dairy farmers in sub-Saharan Africa have failed, primarily because of institutional inadequacies and/or failures and low levels of farmer engagement. Most of the breeding programmes have been implemented in a research based setting (on-station) for many years with minimal farmer participation (Chawala et al., 2017; Mihret et al., 2017). Where production of crossbred cattle for distribution to farmers was the goal, failure to produce large enough numbers of crossbred heifers to make an impact was common. This is mainly because often only the semen of pure dairy bulls was available and its use was promoted through government and project-supported artificial insemination programs. Due to recombination losses, animals with higher exotic upgrades (>75% of exotic dairy blood) have proved to be less resilient and productive compared to their F1 counterparts (Cunningham and Syrstad, 1987). This was not consistent with the farmers' breeding objectives and abilities or with the relevant

production systems, as farmers tended not to have upgraded their practices to match the higher demands of such higher grades. Absence of incentives for sustained national pooled and formal recording, analytics and feedback systems, poor artificial insemination delivery and unavailability of locally adapted but genetically superior proven crossbred bulls are additional factors that have further deteriorated the situation in many Sub-Saharan Africa countries (Philipsson et al., 2011). Animal husbandry and breeding are less sophisticated in sub-Saharan Africa compared to temperate regions. This is because the *Bos indicus* breeds are hardy in terms of disease resistance and have good adaptability to the harsh conditions of the tropical environment. Indigenous breeds are poor milk producers, however, there is evidence that adapting improved Zebu such as Sahiwal, Red Sindhi, Boran and synthetic breed can be an alternative solution for high milk yield in sub-Saharan Africa (Galukunde et al. 2013). The synthetic breed can safely be recommended for milk production in the environment with improved nutrition, disease control coupled with improved management. Assisted reproductive technologies, genomics tools, and established simple recording schemes will provide better opportunities for developing and multiplication improved indigenous breeds and synthetic breeds. The major constraint has been the practical application of this evidence in the improvement of dairy cattle in sub-Saharan Africa. Changes in relevant government policies and support have also significantly affected genetic improvement programmes in sub-Saharan Africa countries.

Additionally, previous attempt to establish sustainable breeding programmes have failed because of the intermittent project-based resources, especially funding and lack of continuity. Farmers and dairy industry actors have not worked together to co-invest in long term breeding programmes, meaning the task often fell to short-term and opportunistic Non-Governmental Organisations and external funding agencies.

The objective of the present study was to identify breeding objectives and to assess the impact of production systems and breed types on dairy cattle

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performance traits. Specifically, the objectives of this study were: (i) to assess the array, clusters and relationships of animal traits studied in the literature that reflect preferences among farmers, scientists and institutions involved in dairy production (ii) to examine dairy cattle production information that could be used to design a sustainable breeding programme in sub-Saharan Africa.

Methodology

Literature search and selection criteria

This review used qualitative analysis and meta-analysis methods. Electronic literature searches were undertaken to identify studies reporting animal performance and farmer's preferred dairy cattle traits in sub-Saharan Africa. Information was retrieved from the electronic databases DiscoverEd, Google Scholar, CAB Abstracts and the International Livestock Research Institute (ILRI) website. These databases included reports, MSc and PhD theses and peer reviewed published papers relating to dairy production in sub-Saharan Africa. The key words used in the search were: smallholder, large-scale farm, dairy, farmer, trait, objective and breed in combination with production, system, environment, sub-Saharan and Africa. Relevant information was recorded in an excel spreadsheet.

The criteria used for selecting publications to be included in the present study were: a) the publication was related to the aim of the study, b) the study described the production system and performance of dairy cattle in small and/or large farms in sub-Saharan Africa, c) the study reported least square means per level of fixed effect adjusted for all other effects in the model. The selected studies offered estimates of least square means for cattle performance traits and corresponding standard errors. Figure 2.1 shows a flow diagram of the selection criteria used for the studies to be included in the present research.

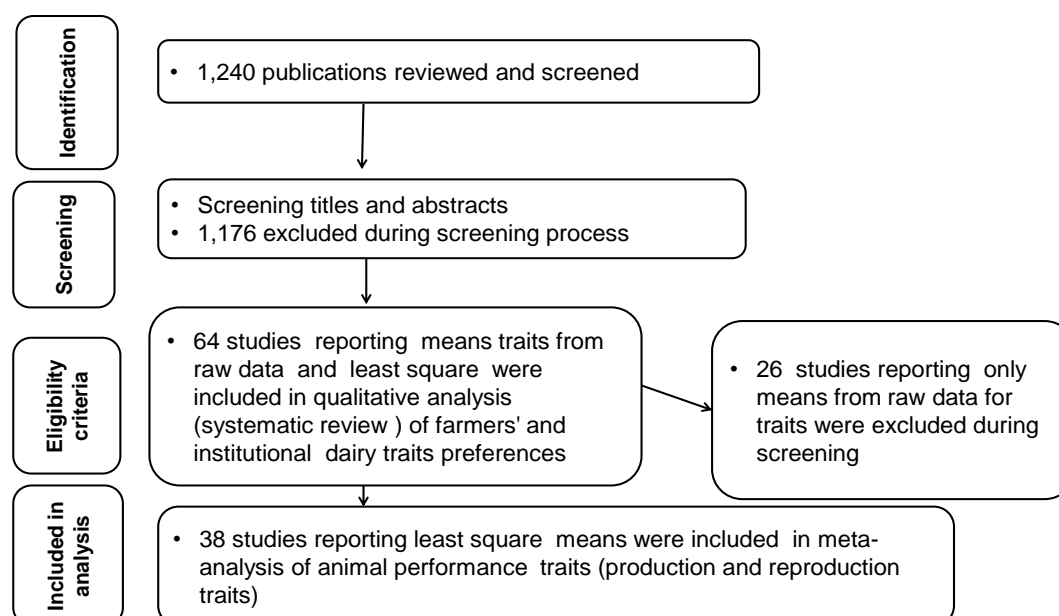


Figure 2.1 Flow chart of study evaluation criteria

Data

Data extraction, entry and coding

In total 1,240 publications were reviewed and screened, from which 64 were selected as relevant for qualitative analysis and 38 for meta-analysis (Supplementary material S1). Data were recorded in an excel file including the authors' last name, year of publication, time period of study, country of study, sample size (n), study design, production system, fixed effects, breed type of animals, traits studied and corresponding estimates per level of a fixed effect adjusted for all other effects in the model. Table 2.1 summarises the selected studies used for qualitative analysis and meta-analysis.

Table 2.1 Summary of selected studies used for qualitative analysis and meta-analysis, sorted by year of publication Summary of selected studies used for qualitative analysis and meta-analysis, sorted by year of publication

Reference ¹	Country	Breed Type ²	Production system ³	Type of analysis ⁴	Study design ⁵	No. of farmers ⁶	No. of animal records ⁷	Traits ⁸
Ayeneshet et al., 2018	Ethiopia	XB	S	Q&M	CS	376	-	P, F
Baur et al., 2017	Malawi	XB	S	Q&M	CS	540	-	P, F
Chawala et al., 2017	Tanzania	XB	L	Q	PR	-	1,003	P, F
Kariuki et al., 2017	Kenya	HF, XB	S	Q	CS	125	-	P, F
Genzebu et al., 2016	Ethiopia	XB	S	Q	CS	130	-	P, F
Mekuria, 2016	Ethiopia	NH, XB,	S	Q&M	CS	249	-	F, C
Hunde et al., 2015	Ethiopia	NH	L	Q&M	PR	-	-	P, F
Kashoma et al., 2015	Tanzania	HF	L	Q&M	PR	-	314	P, F
Kebede, 2015	Ethiopia	HF	S	Q&M	CS	80	154	P, F
Nandolo, 2015	Malawi	NH	L	Q&M	PR	-	373	P, F
Dairy Genetics East Africa (DGEA), 2015a	Kenya	XB	S	Q	PR	696	-	C
DGEA, 2015b	Ethiopia & Tanzania	NH, HF, XB	S	Q&M	CS	-	31,657	P, C
International Livestock Research Institute (ILRI), 2014	Tanzania	XB	S	Q	CS	932	-	C
Kumar et al., 2014	Ethiopia	XB,	S	Q&M	CS	72	475	F
Muasya et al., 2014	Kenya	HF	L	Q&M	PR	-	5,468	P, F

Mungube et al., 2014	Kenya	XB	S	Q	LS	25	250	P, H
Gillah et al., 2014	Tanzania	XB	S	Q	LS	60	1,107	P
Wanjala et al 2014	Kenya	HF, NH, XB	S	Q	S	400	-	P, F, C
Gebreyohannes et al., 2013	Ethiopia	XB	L	Q&M	PR	-	5,507	P
Dinka, 2012	Ethiopia	XB	S	Q	CS	60	250	F
Duguma et al., 2012	Ethiopia	XB	S	Q	CS	72	NA	P, F
Moges, 2012	Ethiopia	XB	S	Q	CS	-	384	F
Massawe, 2011	Tanzania	HF, NH	L	Q&M	PR	-	721	P, F
Marius et al., 2011	Zimbabwe	NH, HF, XB	S	Q	CS	109	-	P, A
Chang'a et al., 2011	Tanzania	XB	S	Q	CS	129	-	A
Mgeni, 2010	Tanzania	XB	S	Q&M	CS & PR	176	664	P, F
Tadesse et al., 2010	Ethiopia	HF	L	Q&M	PR	-	1,230	P, F
Swai et al., 2010	Tanzania	XB	S	Q	CS	200	-	A
Abraha et al., 2009	Ethiopia	XB	S	Q&M	LS	186	36	P, F
Chenyambuga and Mseleko, 2009	Tanzania	XB	S	Q&M	LS	48	-	P, F
Gader et al., 2009	Sudan	HF	L	Q&M	PR	-	1,049	P
Haile et al., 2009	Ethiopia	XB	L	Q&M	PR	-	2,360	P
Yifat et al., 2009	Ethiopia	XB	S	Q&M	CS	287	503	F
Swai et al., 2009	Tanzania	XB	S	Q	LS	-	549	A
Wudu et al., 2007	Ethiopia	XB	S	Q	LS	112	185	A
Asimwe and Kifaro, 2007	Tanzania	XB	S	Q&M	PR	-	2,131	F
Ilatsia et al., 2007	Kenya	XB	L	Q&M	LS	-	25,741	P, F
Lobago et al., 2007	Ethiopia	XB	S	Q&M	LS	24	69	P, F

Mureda and Mekuriaw, 2007	Ethiopia	XB	S	Q&M	CS	-	283	F
Swai et al., 2007	Tanzania	XB	S	Q&M	CS	63	179	F
Msanga and Bee, 2006	Tanzania	XB	S	Q	CS	-	20	A
Ngongoni et al., 2006	Zimbabwe	XB	S	Q	CS	72	-	P, F
Bwire et al 2005	Tanzania	XB	L	Q	PR	-	1,257	P, F
Demeke et al., 2004a	Ethiopia	HF, XB	L	Q	PR	-		F
Demeke et al., 2004b	Ethiopia	HF, XB	L	Q&M	PR	-	2,024	P
Abdelgader et al., 2004	Sudan	HF	L	Q&M	PR	-	1,049	F
Chagunda et al., 2004	Malawi	HF	L	Q&M	PR	-	1,968	F
Kahi and Nitter, 2004	Kenya	HF, NH	L	Q&M	PR	-	1,168	P, F
Kaziboni et al., 2004	Zimbabwe	XB, NH	S	Q&M	CS	82	679	F
Msanga and Bryant, 2004	Tanzania	XB	S	Q&M	LS	-	36	P, F
Bebe et al., 2003a	Kenya	HF, NH	S	Q&M	CS	1,755	-	C
Masama et al., 2003	Zimbabwe	HF, NH, XB	S	Q&M	LS	-	4,392	P, F
Shiferaw et al., 2003	Ethiopia	XB	S	Q&M	PR	-	451	F
Tadesse and Dessie, 2003	Ethiopia	HF, X	L	Q&M	PR	-	608	P, F
Kahi et al., 2000	Kenya	HF, NH, XB	L	Q&M	PR	-	-	P, F
Msanga et al., 2000	Tanzania	XB	S	Q	PR	-	1,086	P
French et al 2001	Zimbabwe	NH	S	Q	CS	50	-	P, A
Negusie et al., 1998	Ethiopia	XB	L	Q&M	PR	-	-	F
Kahi et al., 1999	Kenya	XB	L	Q	PR	-	10,213	P, F
Muhuyi, 1997	Kenya	XB	L	Q	PR	-	6,155	P, F
Kahi et al., 1995	Kenya	XB	L	Q	PR	-	1,443	P
Gitau et al., 1994	Kenya	NH, XB	S	Q	CS	90	-	P, A

Agyemang et al., 1986	Malawi	HF, XB	S	Q	PR	-	-	P, F
Alberro, 1980	Mozambique	HF, XB	L	Q	PR	-	-	P, F

¹References: The list of references used for the qualitative analysis and meta-analysis is given in Supplementary Material S1

²Breed types: Dairy breed: HF = Holstein - Friesian dairy cows, NH = Non Holstein - Friesian dairy cows, XB = Crossbred cows

³Production system: S = smallholder dairy production system, L = large scale dairy production system

⁴Type of analysis: Q = studies used for systematic review, M&Q= studies used for both qualitative analysis and meta- analysis

⁵Study design: CS = cross-sectional survey, LS = longitudinal survey, PR = routine animal recording in a breeding programme both on-farm and on-station

⁶Number of farmers involved in a study

⁷No. of animal performance records: reported number of cow records in the literature

⁸Trait: main traits in the study; P = milk and growth production traits, F = Fertility traits, A = diseases and adaptability traits, C = characterization of dairy production systems

Data analysis

After data extraction, coding and entry, two separate datasets were constructed from the main file. The first dataset included all the traits that were retrieved across different studies. This dataset was used to analyse patterns of traits studied in the literature which might reflect dairy trait preferences of farmers and institutions. The second dataset included least squares means of production and reproduction traits from multiple studies. This dataset was used to quantify the impact of production systems and breeding types on dairy cattle performance.

Qualitative analysis

The first objective was addressed by clustering traits derived across different studies. Cluster analysis is useful for understanding patterns of preferences without making prior assumptions of sample variability (Kaufman and Rousseeuw, 1990). Qualitative data were derived from multiple studies based on the research interests of farmers and institutions. All 64 publications were used for qualitative analysis (systematic review) to assess patterns of animal traits studied in the literature.

A dichotomous coding approach was developed to further investigate the studied traits based on whether they had been previously studied. This method reflects the degree to which traits are researched and documented. Thus, an animal trait addressed in a given study was coded in a binary scale as “1” if it had been previously explored in other studies or “0” if it had not. Our hypothesis was that data availability and patterns of animal traits observed in multiple studies reflects farmers’ and institutional preferences. Smallholder farmers’ interests were captured through cross-sectional and longitudinal survey studies (n=36) while institutional interest was captured from the on-station experiment (n=28) studies. A multivariate technique (cluster data analysis) was used to quantify farmers’ and institutions’ trait preferences.

ClustOfVar an R -package for clustering variables was used to identify the similarity of traits reported from multiple studies (Chavent et al., 2017).

Meta-analysis

The second objective was addressed by conducting a meta-analysis. Thirty-eight (38) publications were used to assess the impact of production systems and breed types on the production performance of dairy cattle. Most of the reviewed publications presented an analysis of more than one least squares mean of animal traits. These least squares means from different levels of fixed effects were treated as independent and were all included in the meta-analysis. Studies reporting only means from raw data for traits were excluded during the screening process (Figure 2.1). In total 1,396 least squares means of traits from multiple studies were available for estimation of the productive and reproductive performance of dairy cattle. The number of studies and least squares means of traits used for the meta-analysis is shown in Table 2.2.

Table 2.2 Number of publications and least squares means of traits used for meta-analysis

Trait	Unit	Number of publication	Number of LS Mean ¹
Age at first calving	Days	20	160
Calving interval	Days	29	339
Number of days open	Days	13	143
Lactation length	Days	37	277
Lactation milk yield	Litres	36	338
Number of services per conception	Count	14	139
Total			1,396

¹LS Mean = Number of least squares means for each trait retrieved from multiple studies

Standard errors were used to weigh the least squares means from different studies according to the perceived level of accuracy dictated by the corresponding sample size. The following formula was used to calculate the

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weight of each least squares mean (Lee et al., 2016) (where, \mathbf{W}_m is weighted least squares mean, \mathbf{SE}_m is standard error of the least squares mean):

$$W_m = 1/SE_m^2$$

Publication bias and variation across studies was assessed using funnel plots and heterogeneity (I^2) statistics using R and the package “meta-package” R Core Team 2018) (Guido, 2018). A mixed effects model was adopted to account for the variation in research design, sample size and statistical design among studies (Greco et al., 2013). The following linear mixed-effects model with production systems and breed types as fixed effects and individual publications as a random effect was used to evaluate production performance traits of dairy cattle (Bates et al., 2014; Henderson, 1982):

$$\mathbf{y} = \mathbf{X}\boldsymbol{\beta} + \mathbf{Z}\mathbf{u} + \boldsymbol{\varepsilon}$$

(\mathbf{y} = vector of weighted population least squares mean in all publications; \mathbf{X} = known design matrix of the fixed effects; $\boldsymbol{\beta}$ = unknown vector of fixed effects parameters to be estimated (i.e production systems and breed types); \mathbf{Z} = known design matrix of the random effects; \mathbf{u} = unknown vector of random effects parameters (publication); $\boldsymbol{\varepsilon}$ = unobserved vector of random errors).

The following assumptions were made: $\mathbf{u} \sim \mathbf{N}(\mathbf{0}, \mathbf{G})$; $\boldsymbol{\varepsilon} \sim \mathbf{N}(\mathbf{0}, \mathbf{R})$; $\text{Cov}[\mathbf{u}, \boldsymbol{\varepsilon}] = \mathbf{0}$ where: \mathbf{G} is a variance-covariance matrix of \mathbf{u} and \mathbf{R} is a variance-covariance matrix of the errors ($\boldsymbol{\varepsilon}$), with $\mathbf{R} = \sigma^2\mathbf{I}$.

Results

The 64 publications examined were from Eastern and Southern Africa. Studies used were dominated by research findings in Eastern Africa (81% from Tanzania, Kenya, Ethiopia and Sudan) compared to Southern Africa (19% from Malawi, Mozambique and Zimbabwe). Close to two thirds (62%) of the data originated from smallholder farmers and the remaining from large scale

farms. On smallholder farms, 67.5% kept crossbred cows and 32.5% had purebreds. Large-scale farms tended to keep mainly purebreds (58.3%) followed by mixed breeds of both purebreds and crossbreds (41.7%).

Farmers' and institutional trait preferences

Figure 2.2 shows the frequency of trait analysis from multiple studies. Reproduction (age at first service, age at first calving, calving interval, days open and number of services per conception), production (milk yield and constituents and lactation length) and disease resistance were the most frequently researched traits. In comparison, temperament, body conformation and growth were the least studied traits. Overall, the results showed that a higher proportion of studies reported reproduction and production traits compared to other traits.

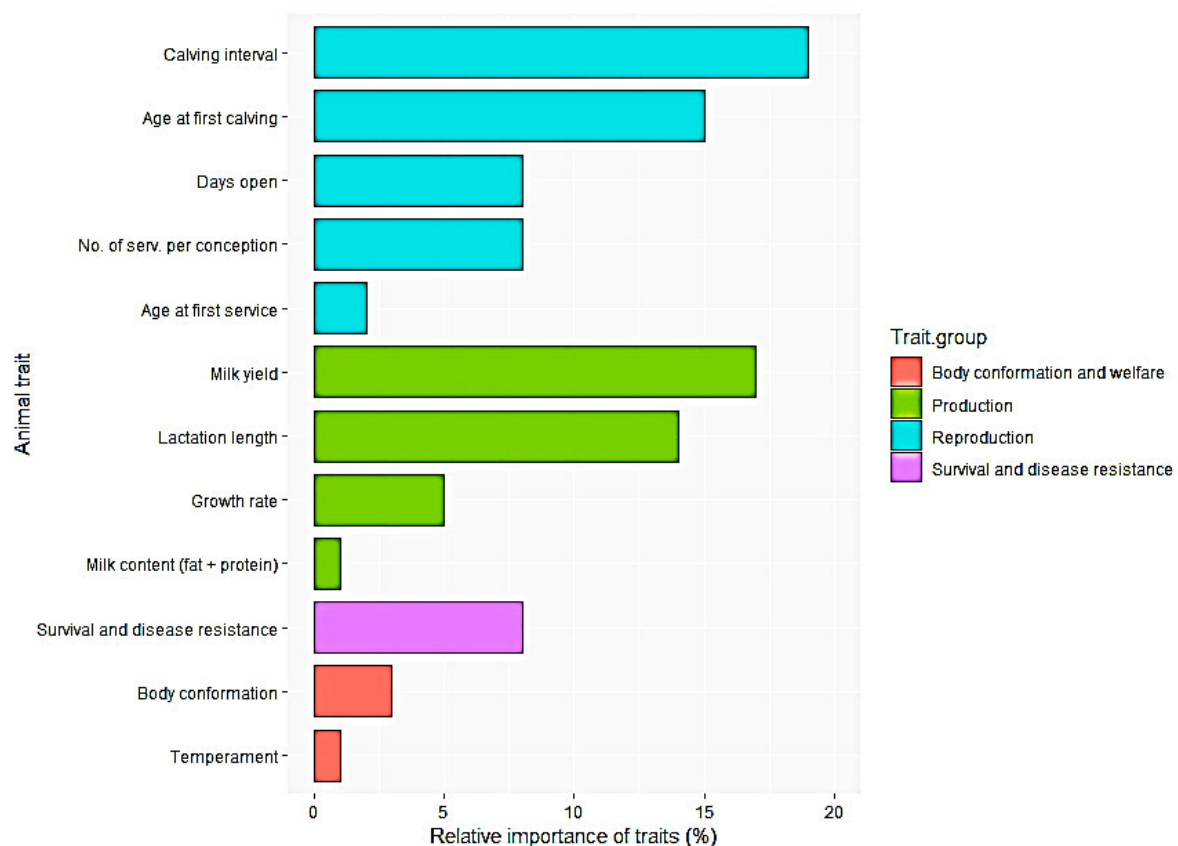


Figure 2.2 Relative importance of animal traits study derived from multiple studies

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Figure 2.3 shows the dendrogram obtained from the cluster analysis of animal traits retrieved from multiple studies. Fifty-six (56%) of studies reporting these traits were participatory (survey) and therefore were considered to reflect farmers' preferences or opinions. The remaining studies reported animal traits based on scientists' and institutions' trait preferences or interest. Four main groups of trait preferences can be identified: i) production in terms of milk yield per lactation, milk constituents (fat and protein) and lactation length, ii) Disease resistance and reproduction; age at first service and calving, days open, number of services per conception, calving interval and survival, iii) body conformation and temperament, iv) growth rate of animals. Survival traits are defined as the ability of animals to survive, grow, reproduce and produce under a stressful environment such as tolerance to extreme temperatures and diseases (Mirkena et al., 2010).

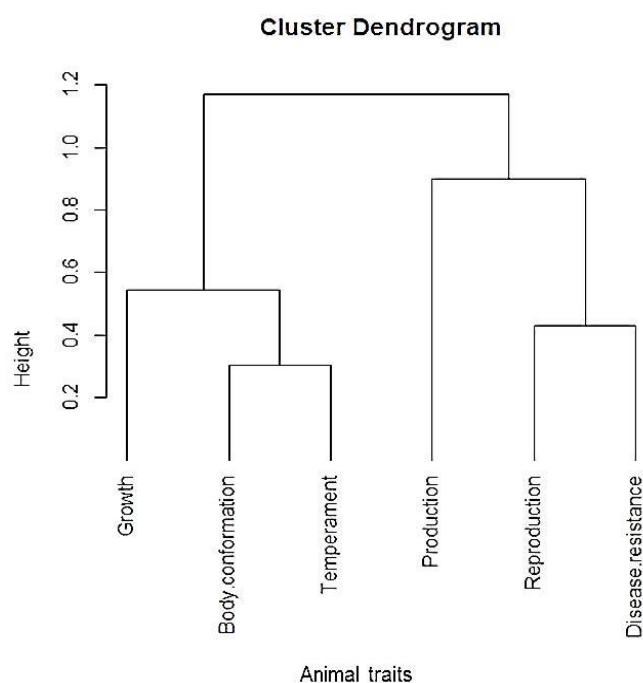


Figure 2.3 Dendrogram of the animal traits preferred by farmers and researchers based on data availability from multiple studies across production systems

Separate cluster analyses were also performed to identify the patterns of animal traits of interest in smallholder and large-scale production systems. Figure 2.4 shows patterns and associations of reproduction, disease

resistance, growth, body confirmation and temperament traits between the two production systems. Overall, the cluster analysis revealed different patterns of trait study in the publications between the two production systems.

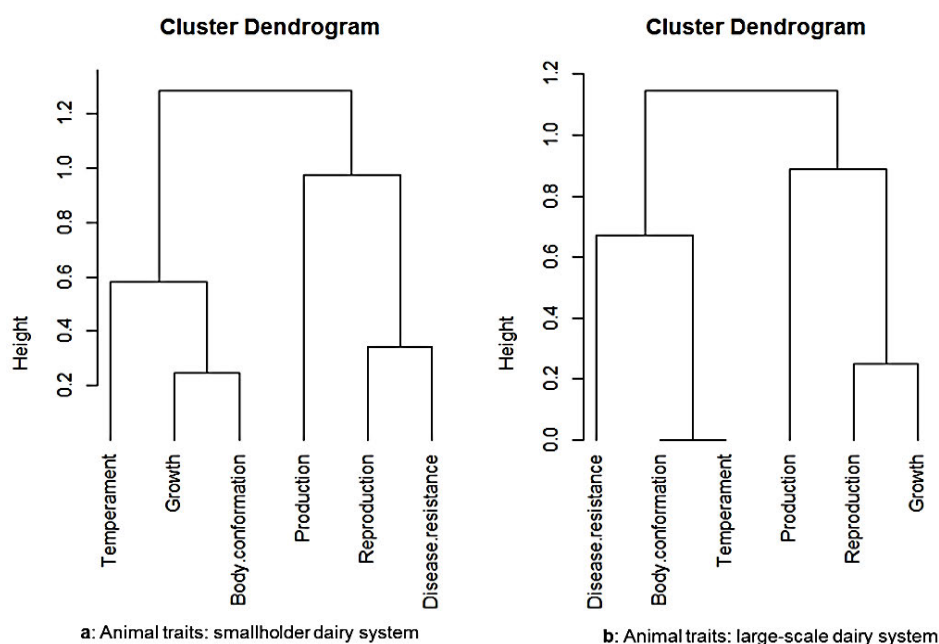


Figure 2.4 Dendrogram of the animal traits preferred by farmers and institutions based on data availability from smallholder (a) and large-scale (b) dairy production systems.

Meta-analysis of production and reproduction performance traits of dairy cattle in sub-Saharan Africa

The heterogeneity (I^2) statistics for production and reproduction performance traits were above 75%, indicating high inconsistency of the data points between studies. The funnel plots showed some signs of asymmetry, indicating bias among the studies (Supplementary Figure S1 to S6). Variability of performance traits across studies was accounted for in the analysis through mixed effects models.

Estimated marginal means for production and reproduction traits from the meta-analysis are presented in Table 2.3. Production system significantly influenced total milk yield for lactation, age at first calving, calving interval and

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number of services per conception ($p < 0.05$). Breed types significantly influenced lactation milk yield ($p < 0.05$). Purebred Holstein-Friesian cows were found to be superior to non-Holstein-Friesian dairy breeds and crossbreeds in terms of milk production. No significant breed differences were found for age at first calving, calving interval, days open and number of services per conception. The interaction between production system and breed type effect on production and reproduction traits was not significant except for age at first calving. When combined, these results show that there is variation in performance among breed types kept by farmers for dairy production and these variations are mainly influenced by production system.

Table 2.3 Estimated marginal means for production and reproduction traits by production systems and breed type

Factor	Level	Traits ¹					
		LMY (litres)	LL (days)	AFC (days)	CI (days)	NSPC (number)	DO (days)
Production systems ²	LF	2,857.0±233.3 ^a	306.2±17.71 ^a	993.2±57.59 ^a	441.9±11.2 ^a	2.1±0.14 ^a	141.7±15.82 ^a
	SH	2,419.8±617.39 ^b	281.4±17.71 ^a	1,321.1±66.28 ^b	482.7±12.34 ^b	1.6±0.13 ^b	168.2±22.21 ^a
Breed types ³	HF	3,148.5±433.00 ^a	288.8±14.68 ^a	1,229.4±80.93 ^a	461.4±10.33 ^a	1.6±0.16 ^a	173.4±26.01 ^a
	NH	2,995.6±456.36 ^a	284.10±14.58 ^a	1,161.9±77.45 ^a	461.5±9.51 ^a	2.01±0.30 ^a	INA
	XB	1,771.1±328.52 ^b	308.5±11.231 ^a	1,080.0±63.44 ^a	464.1±9.46 ^a	1.9±0.10 ^a	136.5±13.75 ^a
Prod x Br ⁴		NS	NS	*	NS	NS	NS

Note: Estimated marginal means with a different superscript in the same column are significantly different from each other (p<0.05)

¹Trait: LMY: lactation milk yield, LL: lactation length, AFC: age at first calving, CI: calving interval, NSPC: number of service per conception, DO: days open

²Production systems: LF = large-scale dairy production system, SH = smallholder dairy production system

³Breed types: HF = Holstein -Friesian breeds, NH = Non Holstein - Friesian breeds, XB = Crossbreeds

⁴Prod x Br = production system and breed types interaction effect

INA: inadequate information for data analysis, *: significance level p<0.05

Stakeholders and institutional support for genetic improvement

The literature review shows that animal performance traits are primarily researched and reported by government research and extension service departments. Sixty-two (62%) of studies reporting on animal performance traits were from smallholder dairy farmers. Figure 2.5 shows the proportion of smallholder and large-scale farms reporting on the performance traits. The literature review also showed that genetic improvement activities are carried out through funding from government and recently the majority of the research activities are being undertaken by development agencies, especially Non-Governmental Organisations. Government research funding initiatives have been through livestock sector lead ministries, national agricultural research organisations and artificial insemination companies. The International Livestock Research Institute and other international development partners have technically and financially supported dairy improvement activities in sub-Saharan Africa.

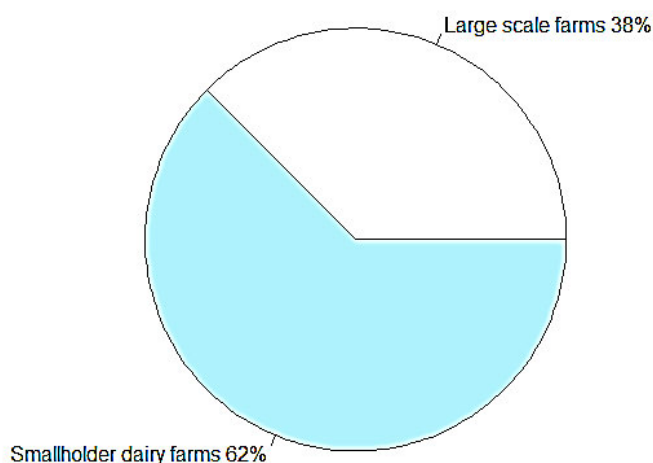


Figure 2.5 Proportion of smallholder and large scale dairy farm studies reporting on performance traits

Discussion

The goal of this study was to assess the patterns of traits studied in the literature that reflect preferences among dairy farmers and institutions, and to examine the impact of production system and breed type on dairy cattle performance traits. In reviewing the literature, research priorities and possible solutions to problems associated with genetic dairy cattle improvement in sub-Saharan African countries were also highlighted.

Patterns of trait preferences among farmers and institutions involved in dairy production across production systems

Patterns of the traits most frequently studied/reported and therefore assumed to be preferred, included reproduction, production and disease resistance traits. The majority of the studies were carried out by national research institutions which are part of the government. Even though there is an extensive literature highlighting the importance of dairy cattle in sub-Saharan Africa, only 64 studies out of 1,176 were included in the systematic review and 38 in the meta-analyses. A large number of studies were excluded due to the fact, that the data required for systematic review and meta-analysis for this study were not available. Regarding the systematic review, data included in the qualitative analysis were from on-station experiments, private large farms, longitudinal and cross-sectional surveys in smallholder dairy farms. In order to ensure a systematic review process, a precise and consistent coding of the animal traits was adopted. Cross-sectional and longitudinal survey studies were predominant compared to on-station and large scale farms studies. Farmers participating in cross-sectional surveys ranged from 24 to 1,755, with a median of 112 farmers. Pertaining to the meta-analyses, 38 out of 64 publications included in the systematic review were used in the meta-analyses. On the other hand, the number of animal records in published articles and reports varied widely ranging from 20 to 31657, with a median of 721 records. Two fixed effects of breed types and production systems were identified from the 38 papers, and meta-analyses were performed to quantify

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the impact of these factors on the identified animal traits. Milk yield and calving interval traits were more frequently reported than milk constituents (fat and protein percentages) and somatic cell count because the milk pricing policies are mainly volume based. In previous research, the main breeding goal reported for dairy farmers was increased milk yield of improved dairy cattle, for income generation and improved nutrition through home-consumption of milk (Duguma and Janssens, 2016; Marius et al., 2011). Other animal traits such as temperament, body conformation and growth traits were rarely focused on.

In the present study we used a cluster analysis across production systems and grouped these traits into four major groups. Reproduction, adaptability and disease resistance traits had previously been studied together and were grouped here in cluster one. Key reproduction traits studied included age at first service, age at first calving, calving interval, days open and number of services per conception. Low fertility is common in large-scale and smallholder dairy production systems. This is mainly due to a high number of services per conception, long calving intervals, older age at first calving and more days open. Additionally, inadequate nutrition, poor heat detection, poor artificial insemination skills, timing and operating conditions, (including lack of reliable liquid nitrogen supply and poor equipment) are partly responsible for the poor fertility of dairy cows. Natural pastures, fodder and crop residues as the main source of feed for dairy cattle are limited both in quantity and quality. Seasonal availability and sub-optimal quality of feeds results in poor animal growth, poor oestrus behaviour, disease and abortions. Overall, poor performance leads to low milk production.

The same cluster (cluster 1) included adaptability and disease resistance, which is defined as the ability of animals to survive, grow, reproduce and produce under stressful environments such as extreme temperatures, humidity and disease challenges (Bebe et al., 2003a; Mwacharo and Drucker 2005). Diseases and internal and external parasite prevalence have a major influence on the choice of breeds for milk yield and adaptability to the environment. Diseases and parasites cause significant biological and

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economic losses due to reduced body weight, decreased milk yield, treatment costs and high mortality rates. The most fatal diseases such as East Coast Fever, Anaplasmosis, Babesiosis and Cowdriosis can be controlled by regular dipping and vaccinations of cattle. Tick-borne diseases have been reported as one of the major causes of death for various categories of cattle. Apart from fluke, gastro-intestinal parasites are of more importance in calves (French et al., 2001; Swai et al., 2009).

Regular application of acaricides through dipping or spraying and vaccinations are the key measures for controlling tick-borne diseases and deworming animals for intestinal parasites. There is a need for strategic introgression of genes that influence adaptation, such as slick genes (Davis et al. 2017), in systems where ambient temperatures and humidity are high; genes for tolerance to trypanosomes (Noyes et al., 2011) where trypanosomosis are prevalent; and tick tolerance genes (Mapholi et al., 2016), where tick populations are high. However, the accessibility to individuals with the desired introgressed genes to enable mass availability to farmers still remains challenging, given regulatory concerns as well as a lack of systems to locally multiply and efficiently deliver them.

Production traits which included total milk yield for lactation, lactation length and milk constituents were grouped in a second cluster. Preferences for milk yield were influenced by several external pressures including, but not limited to, favourable government policies towards dairy production and improvement in infrastructure such as roads, electricity supply and markets. Milk yield, in comparison to milk component or quality traits, has received more emphasis in trait selection because volume-based pricing policies are predominant. In smallholder dairy farms where farmers were interested in improving milk yield, they mostly achieved this through upgrading local breeds by using exotic commercial dairy stock. However, larger farms tended to keep a large number of purebred commercial dairy breeds and crossbred cows. Most of the past studies tended to focus on better managed herds and the results were therefore biased towards higher producing cows. When a random

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sampling strategy was adopted, thus removing such biases, lower levels of production were observed among smallholder herds (DGEA, 2015). Bebe et al., (2003a) mentioned that poor access to veterinary services and high feeding costs are key reasons for farmers' preference for crossbred dairy cattle.

The third cluster included growth rate and body conformation traits. These were described in previous studies as market and functional traits. The focus of these previous studies was on the development of strategies in response to market demands in relation to live animals and dairy products, as well as animal feed utilisation efficiency.

Feed conversion efficiency is a key trait for increasing production and profitability of the dairy industry. It has been reported that feed cost accounts for between 60 to 70% of the total milk production costs in smallholder systems (Duguma and Janssens 2016). For example, the majority of smallholder dairy farmers practice a cut and carry feeding system and cows are housed throughout the year. Therefore, the more efficiently a cow converts the available feed resources into milk, the better.

Selecting animals with higher feed conversion efficiency would increase both growth rate and milk production. Spurlock et al., (2012) reported a moderate positive genetic correlation of 0.42 to 0.72 between gross feed efficiency and energy corrected milk production in temperate countries. The majority of on-going and previous animal breeding programmes in sub-Saharan Africa have concentrated on increasing milk yield, with little attention on reducing the cost of production. Studies aimed at investigating purebred and crossbred differences in feed conversion efficiency would help to identify animal genotypes that best suit low input production systems, given that such systems are characterised by feed and water scarcity. The genetic correlation between feed efficiency and other production traits in low input production systems needs to be quantified. This will provide baseline information on the

variation of animals within and between breeds for feed efficiency in relation to other production and reproduction traits.

The market value of young stock and mature dairy cattle in the traditional markets is influenced by body conformation traits such as udder structure and body size. Body size is related to breed type and is often used for matching bulls and cows for mating (DGEA, 2015). Physical appraisal of animals is also used as a way of selecting the best cows and bulls. Conversely, milk production and marketing tend to follow the pattern of feed and water availability. A decline in milk yield occurs during the dry season mainly due to a shortage of feed and water. Milk marketing in sub-Saharan Africa faces several challenges, including unregulated markets and low milk quality caused by poor handling and storage facilities. A study carried out in Tanzania on milk price sensitivity showed that season and location had a significant effect on producer milk prices (Wassena et al., 2015). The practical implication of the current findings is that genetic improvement programmes should be conducted in parallel with market studies of dairy products and dairy chain stakeholders to ensure returns on invested inputs.

The final trait cluster included animal temperament traits. Temperament is an important complementary trait that should be easy to deal with. Haskell et al. (2014) reported a positive correlation between temperament and production traits. Only cows that are exceptionally productive but with a good temperament should be selected as bull-dams.

Patterns of trait preferences between production systems

Production system significantly influenced animal trait preferences. Farmers' and institutions trait preferences differed between production systems. Cluster analysis showed that studies involving smallholder dairy farmers put an equal emphasis on reproduction and disease resistance, and growth and body conformation. Conversely, studies focusing on large-scale farmers' gave equal emphasis to reproduction and growth and body conformation and temperament. However, production traits had similar study

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patterns in the two production systems. Variations in grouping of preference traits between production systems reflect farmers' and institutions' differing opinions on animal traits of interest. These findings provide an idea of the patterns of animal traits analysed in multiple studies which are important to farmers', scientists and institutions.

Production performance of dairy cattle

Our results indicate that production and reproduction traits are significantly influenced by production system. Significantly higher milk production in large-scale farms may be attributed to a proportion of pure exotic commercial dairy breeds compared with crossbreds in smallholder dairy farms. In addition, appropriate nutrition at different stages of pregnancy and lactation, coupled with improved management practices, are among the factors leading to positive animal performance in large-scale farms (Kanuya et al., 2014; Kivaria et al., 2006). Shorter calving intervals in large-scale farms may be attributed to fewer days open as indicated in the present study. Significantly higher numbers of insemination per conception in large-scale farms could be associated with difficulties in heat detection in large herds. Poor conception rates, older age at first service and calving, and longer calving intervals tend to reduce lifelong cow productivity and optimal profitability (Oltenacu and Broom, 2010). Older age at first calving also increases the generation interval and thus slows the rate of genetic gain.

Purebred dairy cows (Holstein-Friesian, Jersey, Ayrshire and Guernsey) had higher lactation milk yield compared to crossbred cows (*Bos taurus x Bos indicus*). The average lactation milk yield for purebred exotic dairy cattle in sub-Saharan Africa was found to be low compared to levels attained by similar breeds in temperate regions of the world. For example, lactation milk yield for purebred Friesian cows reported in this study (3,148.5±433.00 litres) was low compared to levels of more than 7,000 litres per lactation produced by the same breeds under different management conditions (AHDB 2017). The current study gives an overview of the potential of exotic commercial dairy

cattle and their crosses compared to indigenous breeds. The observed level of milk production performance is far from the true genetic potential of purebreds reported in different production environments in temperate regions. These results need to be interpreted with caution because of the “genotype by environment” interaction effects, which may explain the variation of performance for different genotypes in diverse production environments. Mwacharo et al. (2008) reported huge productivity gaps in similar breeds raised in different regions and production systems. These differences show that efforts need to be made to properly match genotypes with environments.

Evidence from previous studies indicates that the optimum milk productivity in sub-Saharan Africa can be achieved for dairy cattle with 50 to 75% *Bos taurus* genes (Kiwuwa et al., 1983; Kahi et al., 1999, Msanga et al., 2000; Goshu 2005). Studies have indicated that smallholder dairy farmers keeping crossbred cows generate more profit than those keeping purebred or indigenous breeds (Demeke et al., 2004; Gader et al., 2007; Goshu, 2005). While more emphasis is placed on breeding F1 for dairy production, the key challenge of this breeding strategy has been in maintaining the F1 population. Kahi et al. (1999) suggested a breeding strategy involving crossing different breeds to produce synthetic breeds for milk production in the tropics. The use of synthetic breeds has been proposed mainly due to its current technical feasibility using genomic and reproductive technology and the existence of large crossbred populations and is more likely to optimise heterosis and gene combinations (Mwai, 2015).

However, to realise the economic impact from the dairy sector, attention must be focused on the design and implementation of breeding programmes that allow the continued production of F1 progeny. Alternatively, long-term breeding strategies need to be designed to utilise F1s and higher exotic grades, select these and stabilize the levels of component breeds, by coming up with appropriate synthetic breeds for different agro-ecological zones. The African Dairy Genetic Gains Project (ADGG) is currently developing a sustainable dairy cattle genetic improvement programme for sub-Saharan

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Africa. The key objectives of the programme are to develop active National Dairy Performance Centres, on-farm data capture systems and to identify and certify crossbred bulls for artificial insemination and on-farm breeding of cows by innovatively using genomic tools (Mwai, 2015).

Due to a shortage of improved dairy breeds, smallholder farmers have been using any available breed or crossbred cattle from large farms (Ngongoni et al., 2006; Ojango et al., 2017). Furthermore, due to the lack of pedigree and performance recording and uncontrolled crossbreeding, farmers have been buying dairy heifers with unknown pedigrees and breed composition information (Bebe et al., 2003a). Other limiting factors for increased productivity include challenges related to disease, seasonal feed availability and poor breeding infrastructure. Thus, investment in proper breeding strategies, disease control and breeding infrastructure are crucial for optimum productivity to be achieved.

Institutional support for genetic improvement

Most of the dairy production research has been conducted by government institutions and livestock lead Ministries. Many countries in sub-Saharan Africa have formulated pro-dairy productivity improvement policies and are at different stages of implementing the relevant strategies. These activities are well documented (Kenyan Government, 2010; Michael et al., 2017; Shapiro et al., 2015). However, the existing breeding strategies encourage importation of exotic dairy breeds for crossbreeding with indigenous breeds. Artificial insemination as a means of delivering improved genetics has not been fully exploited (Dairy Genetics East Africa (DGEA), 2015; International Livestock Research Institute (ILRI), 2012; Kurwijila and Bennet 2011; Rege et al., 2011). Past and current policies that predominantly support public delivery of artificial insemination services is partly responsible for the limited success, particularly considering the dwindling levels of public investment in the related infrastructure; such as bull studs, distribution and availability of liquid nitrogen and considering poor motivation of technicians. All

of these factors have an effect on farmers' confidence in artificial insemination. To reverse this trend a critical review of dairy policies, in conjunction with more efficient institutional arrangements, are needed to promote increased private participation and delivery of more productive and resilient dairy genetics.

To transform and sustainably improve the smallholder dairy industry, the following actions need to be taken:

- a) There is a need to have comprehensive dairy recording schemes established and implemented, including the priority traits addressed in the present study, to enable realisation of clearly defined breeding objectives. A functional recording scheme will enable identification of superior bulls and bull-dams for different production environments. To achieve a sustainable recording scheme, farmers must see direct and immediate benefits from participating in the recording programme. For example, it has been suggested that quick feedback on individual farm performance may drive farmers to participate in the recording programmes (Mwai, 2015). The current herd performance recording system introduced by the International Livestock Research Institute in Tanzania and Ethiopia needs to be adopted to provide sustainable dairy cattle genetic gains (<https://www.ilri.org/node/40458>). A major constraint at present is the lack of sufficient information to allow the estimation of genetic parameters from smallholder dairy farmers.
- b) A more efficient private artificial insemination delivery system involving public and private organisations needs to be established and implemented.
- c) As dairy farmers' conditions are variable and, require different dairy genetics, Government-run artificial insemination (AI) centres and commercial breeding companies should be responsible for developing and making available a wide range of animal genotypes for farmers to choose from. This can be achieved through multi-country genetic evaluations as is currently undertaken by Interbull (Powell and

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VanRaden, 2002). Genomic selection is feasible, even using limited records among crossbreeds (Brown et al., 2016). There is a need to have crossbred bull semen available from the top bulls for those farmers whose conditions do not suit the top purebred commercial dairy breeds, especially the Holstein-Friesians. Additionally, extensive use of assisted reproduction technologies can help to multiply in-calf heifers to meet farmers' demands for improved breeds.

- d) There is a need for a more enabling policy environment that allows exchange of appropriate dairy genetics between countries and, more importantly, that drives the dairy market. Related to this, better infrastructure and policies would enable farmers to access technical and market information in a timely manner. Better access roads and electricity connections would drive down input costs, while at the same time allowing farmers to process their own feed and to even preserve milk by bulk cooling it prior to selling to processors.

Institutional support for enhancing feed availability throughout the year

Feed scarcity has been ranked as a major challenge for increasing milk productivity in smallholder dairy farms (Atuhaire et al., 2014; Duguma et al., 2015). In developed countries, animal feed quality and availability are not limiting. In sub-Saharan Africa the opposite is the case, especially during the dry season given that feed availability is mainly determined by the amount and distribution of rainfall and feed conservation is rarely practiced. However, conservation strategies exist and when appropriately practiced such challenges are easily overcome (Bebe et al., 2002; Lukuyu et al., 2011; Katongole et al., 2012).

Promoting feed or fodder markets and effectively linking smallholders to such markets would solve the issues related to feed shortage. There is a need to advocate feed centres to allow commercialisation of feeds. Knowledge on agribusiness towards establishing feed centres is required to allow commercialisation of feeds and forages. One way in which this can be

achieved is through the promotion of improved dual-purpose crops. Some crops like maize, wheat, sorghum, and millet are dual purpose: Their grain provides food for humans and their residues are used as feed for livestock (Herrero et al., 2010). Increasingly, farmers in mixed crop-livestock systems value the crop residues as much as the grain owing to their importance as a feed for livestock, particularly in the dry season and hence giving an assurance of adequate feed supplies all year round (Blümmel and Rao, 2006).

Innovations relating to forage availability, production, conservation, processing and fortification of crop by-product by youth and through local production should be supported and promoted. Leveraging local artisans in partnership with academic institutions in designing and fabricating simple machines for feed manufacturing and forage conservation is a better option towards sustainable dairy productivity.

Priorities for future research

Non-significant differences for fertility traits between purebreds and crossbreds found in the present study indicate that crossbred dairy cattle are more favourable for low and medium production systems than purebred cattle. Crossbred cows have more advantages in terms of disease tolerance and low feed requirements compared with purebreds. Intensified selection needs to be carried out within crossbred herds to increase productivity. The following list of research priorities will provide a better future for the dairy industry in sub-Saharan Africa.

- Future research needs to focus on developing farmer-led breeding objectives for dairy cattle in different production systems.
- Currently, a comprehensive on-farm assessment of crosses comprising different breed combinations and levels is being carried out within the ADGG programme. Future research needs to focus on cost effective semen delivery, appropriate mechanisms of genetic delivery and mating strategies of the selected sires /semen.

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- Research should be carried out to assess the feasibility, application and adoption of novel assisted reproductive technologies such as artificial insemination using sexed semen and Multiple Ovulation Embryo Transfer, and how these can be efficiently delivered.

Conclusions

The current study has documented dairy cattle breeding objectives and the impact of sub-Saharan African production systems on production and reproductive performance of purebred and crossbred dairy cattle. The results of this study indicate that production and reproduction traits are significantly influenced by production system and breed type. The traits most frequently assessed in smallholder and large-scale farms are reproduction, production and disease resistance. Butter fat and protein content, temperament and total milk somatic cell count are rarely a focus in the literature mainly because of the milk pricing policies that are mainly volume based. This study suggests that production systems and genetics play a large role in increased dairy productivity in sub-Saharan Africa. Future dairy research should place a greater emphasis on the interactions between improved feeding, disease control and genetics at a production system level to inform profitable combinations of animal traits.

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Supplementary Figure S1 - S6: Bias and Sensitivity Analysis

Funnel plots for performance traits

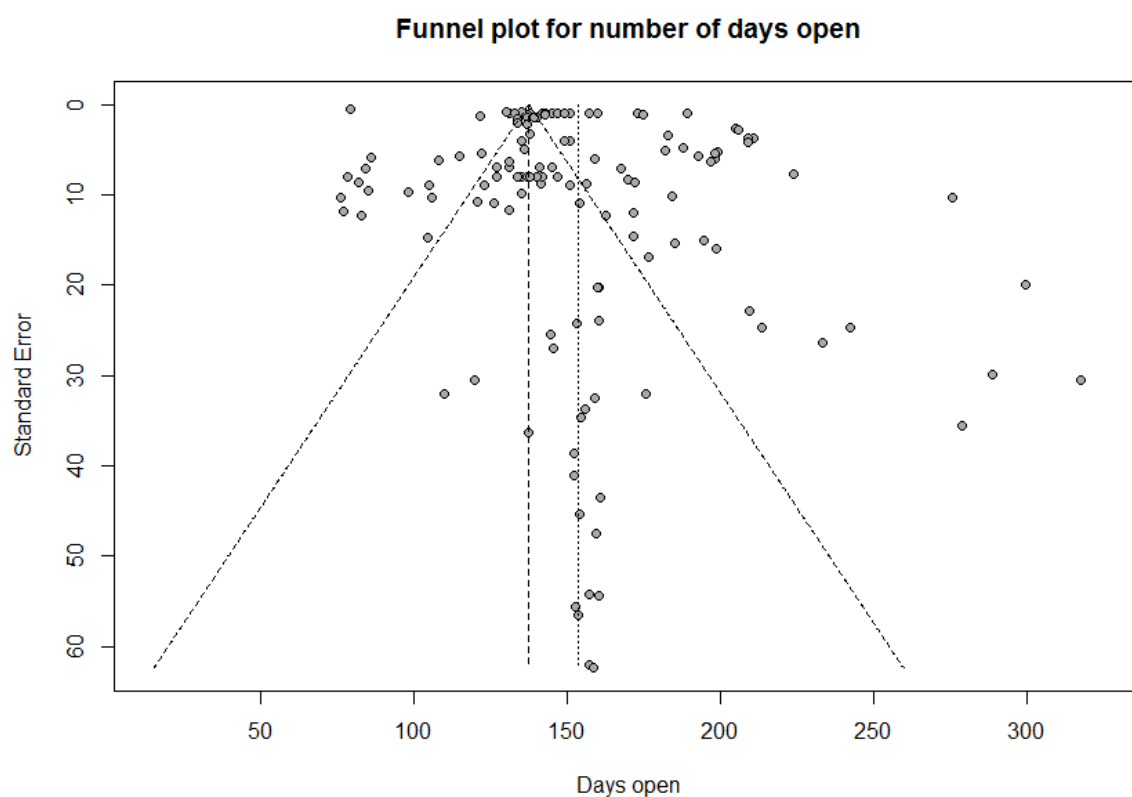


Figure S1: Funnel plot for number of days open

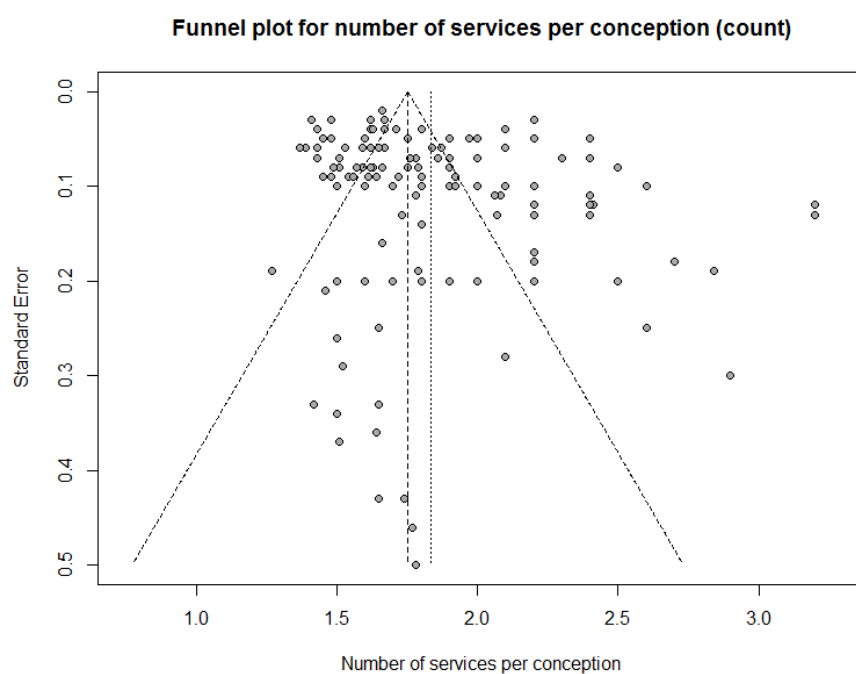


Figure S2: Funnel plot for number of services per conception (count)

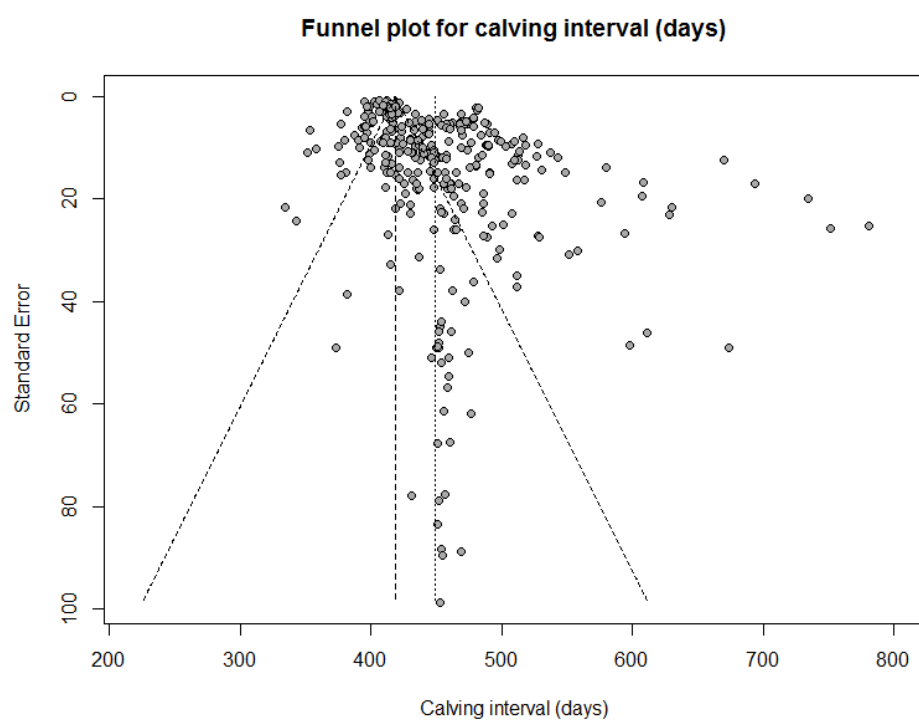


Figure S3: Funnel plot for calving interval (days)

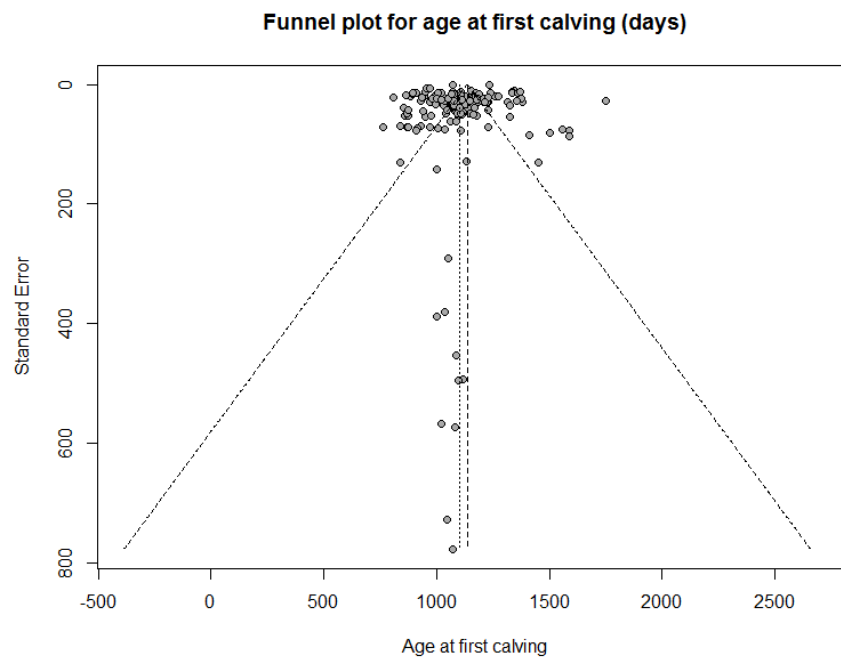


Figure S4: Funnel plot for age at first calving (days)

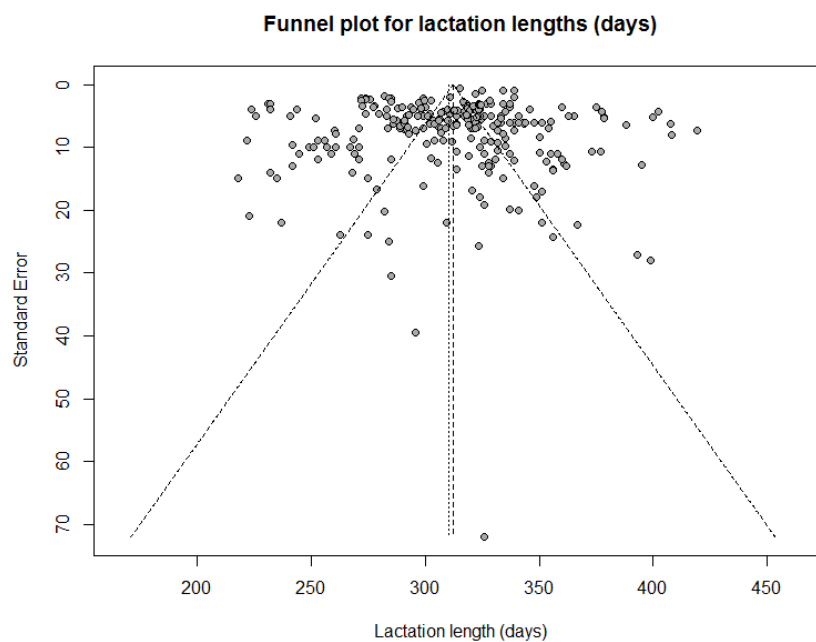


Figure S5:

Funnel plot for lactation length (days)

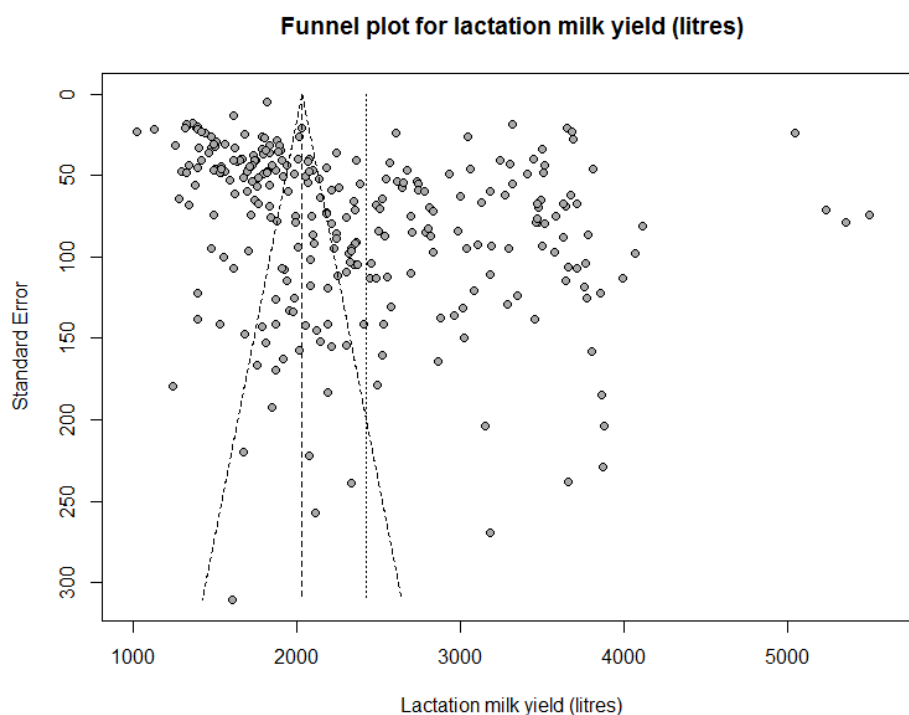


Figure S6: Funnel plot for lactation milk yield (litres)

2.4 Chapter conclusion

This chapter has highlighted past and present animal traits preferred by farmers and institutions. Overall, qualitative analysis and meta-analysis of published findings show a scientific preference towards the following traits: age at first service, age at first calving, calving interval, days open and number of services per conception, milk yield and disease resistance. Among these traits, temperament, milk butterfat and protein were the least studied traits mainly due to current payment systems which are based on milk volume. Indeed from the literature review, we have identified traits that have featured significantly in previous and current literature. However, there is no clear distinction from the literature on which animal traits and breeding strategies should be adopted for dairy improvement in Sub-Saharan Africa. Centralised breeding programmes operated by the government and private large-scale farms have been used as

Chapter 2: Review of breeding goals and dairy cattle performance

a main source of best sires for genetic improvement in smallholder dairy farming systems. The commonly adopted breeding strategies are either closed or open nucleus breeding schemes. However, from the meta-analysis study in this chapter we have found that the performance of dairy cattle was higher in large-scale farms and centrally based breeding stations compared to smallholder dairy farms. The next chapter explores the level of genetic progress that have been achieved in centrally based breeding programmes, using Mpwapwa cattle breeding programme in Tanzania as a case study.

**Chapter 3 Phenotypic and genetic parameters
for selected production and
reproduction traits of Mpwapwa
cattle in low-input production
systems**

3.1 Chapter introduction

The previous chapter reviewed different studies on animal traits which have featured prominently in the previous and current literature. This analysis showed that both pure breeding and crossbreeding strategies using imported exotic dairy cattle (*Bos taurus*) from temperate climates and indigenous breeds (*Bos indicus*) have been adopted to enhance dairy production. The governments in Sub-Saharan African countries have been mainly responsible for planning and installing necessary livestock breeding infrastructures. However, the major constraint of the breeding programmes at present is lack of specific knowledge on suitable types of dairy cattle and breeding strategies for different agro-ecological zones and production systems. The present chapter examines a long-term government-led dairy cattle breeding programme of a dual purpose breed for the smallholder dairy farmers in low-medium input systems in Tanzania. The aim was to examine the genetic progress in top-down breeding programmes, which was designed on the basis of government and researchers interest. Genetic parameters and genetic progress achieved over the past four decades through nucleus breeding programme were studied. This chapter addresses objective two of the thesis. The body of this chapter consists of a scientific manuscript that has been published in the South African Journal of Animal Science as:

Chawala, A. R., Banos, G., Komwihangilo, D. M., Peters, A., & Chagunda, M. G. G. (2017). Phenotypic and genetic parameters for selected production and reproduction traits of Mpwapwa cattle in low-input production systems. South African Journal of Animal Science, 47(3), pp.307-319. ISSN 0375-1589. <https://doi.org/10.4314/sajas.v47i3.7>.

The PhD candidate conducted all the work related to this chapter including developing the research question, data extraction, data analysis and manuscript writing. The study was conducted under guidance from his supervisors and in collaboration with the remaining authors of the manuscript.

3.2 Manuscript

Phenotypic and genetic parameters for selected production and reproduction traits of Mpwapwa cattle in low-input production systems

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Abstract

The objective of this study was to assess the genetic improvement programme of the Mpwapwa dairy cattle breed over the past four decades, based on on-station selection and breeding. Estimates of genetic parameters and genetic trends for total lactation milk yield (LMY), 305-day lactation milk yield (305LMY), lactation length (LL), age at first calving (AFC), and calving interval (CI) were derived. The study used 1,003 lactation records from 385 cows and 78 sires collected from 1967 to 2012. Genetic parameters were estimated using an animal model procedure with ASReml software. The heritability for LMY and 305LMY were moderately high (0.33 ± 0.11 – 0.44 ± 0.04) and low for LL ($0.13 \pm 0.17.0$). Repeatability for LMY and 305LMY was high (0.62 ± 0.04 – 0.70 ± 0.03) and moderate for LL (0.27 ± 0.06). The heritability for AFC (0.13 ± 0.11) and CI (0.10 ± 0.05) were low. The repeatability for CI was low ($0.10 \pm$

0.05). Genetic correlation of 305LMY with LMY and CI were 0.87 ± 0.02 and -0.06 ± 0.009 , respectively, while the corresponding phenotypic correlation estimates were 0.82 ± 0.01 and -0.01 ± 0.001 . Variation among animal estimated breeding values (EBV) was significant, suggesting that selection to improve these traits is feasible. Thirty seven out of 78 sires had favourable EBV (0–900 kg) for milk yield, which suggests that selection for specific sires could result in increased LMY. Annual rates of sires EBV change for 305LMY, LL, CI, and AFC were -0.3kg, -0.05, 0.15, and -0.14 days, respectively. All these traits showed that a decline in genetic progress for Mpwapwa dairy cattle in the on-station breeding programme.

Keywords: genetic correlation, genetic trend, milk yield, fertility, variance components

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Introduction

The realized productivity of indigenous breeds in the tropics is generally low, with estimates of lactation milk yield ranging from 300 to 1,100 kg (Rege *et al.*, 2001; Tadesse & Dessie, 2003). Crossbreeding of tropical indigenous breeds with temperate dairy breeds has been used in various countries as a means of increasing milk production and as a major strategy that has contributed to improving and expanding the dairy cattle population and milk production in the tropics (Cunningham & Syrstad, 1987). Dual-purpose breeds with mixed zebu (*Bos indicus*) and temperate breeds (*Bos taurus*) have shown increased productivity in low-input production systems (Peixoto *et al.*, 2006; Madalena *et al.*, 2012). Most of the countries in sub-Saharan Africa have chosen Holstein-Friesian, Ayrshire, Jersey, and their corresponding crosses with *Bos indicus* for dairy production. With dairy intensification increasing, farmers have adopted high-producing grade exotic *Bos taurus* breeds (Chagunda *et al.*, 2015). However, farmers in low-potential areas have opted

to use genotypes with unique genetic characteristics, such as adaptation to heat and drought, tolerance to disease, and efficient utilization of low-quality forages (Gebreyohannes *et al.*, 2013).

In Tanzania, the Mpwapwa breed, a composite dual-purpose breed suitable for milk and meat production in medium - to low-input production environments, was created by crossing East African Zebu, Indian Zebu, and European dairy breeds, mainly Ayrshire. Establishing the Mpwapwa breed started in the 1920s and ended in 1958 (Kiwuwa & Kyomo, 1970; Rushalaza & Kasonta, 1993). Since then, the breed has been kept for both milk and meat production. According to Kiwuwa & Kyomo (1970), the genetic constitution of Mpwapwa cattle consists of 32% Red Sindhi, 30% Sahiwal, 19% Tanganyika Shorthorn Zebu (TSZ), 11% Boran, and 8% *Bos taurus*, mainly Ayrshire. The breeding goal was for cows to produce 2,300 kg of milk yield per 305-day lactation and for steers to reach a carcass of 230 kg in less than four years in low-input dairy production systems (Syrstad, 1990; Bwire *et al.*, 2005). A nucleus was established in 1958 to drive the breeding programme (Syrstad, 1990).

The major challenge has been how to scale up a breeding programme to cover the needs of a wider breeder and consumer community. The breed multiplication plan has not been efficient, owing to a high turnover of animal breeding experts, disease outbreaks, and policy changes (Wilson, 2009). The challenge has been how to multiply a large number of animals and distribute them to farmers. For example, in the 1990s, the Mpwapwa cattle population was reduced because of mortalities caused by East Coast Fever (ECF), which led to the near extinction of the breed (Bwire *et al.*, 2005). The low Mpwapwa cattle population (<1,000 females) had led the Food Agriculture Organization of the United Nations (FAO, Rome) to characterise Mpwapwa cattle breed as being at risk of extinction (Syrstad, 1990; Rege, 1999). However, multiplication efforts from 1999 onwards have increased the population of the breed owing to farmers' increased demand for the improved cows and bulls. The efforts have involved multiplication of the pure Mpwapwa breed and intensification of

Chapter 3: Genetic progress in centrally based breeding programmes

the increase in number of the animals by backcrossing the present pure Mpwapwa with Boran and Sahiwal. The assumption was that Mpwapwa breed production potential is on par with Sahiwal, while Boran cows were chosen because they are known to be better milkers than TSZ (Bwire *et al.*, 2005).

The target of 2,300 kg of milk per 305-day lactation has not been realized, while the goal of 230 kg carcass per steer at the age of less than four was realized in 1985. There have been efforts to introduce Mpwapwa cattle on-farm since the 1970s under an open nucleus breeding schemes. The breed performance on-farm showed that Mpwapwa cows were yielding four times more milk and had higher growth rates than TSZ cows (Rushalaza & Kasonta, 1993). The breed has been widely accepted by the community owing to its adequate milk and meat yield, disease resistance, and the ability of the bulls to be used for draught power (Komwihangilo *et al.*, 2009).

The selection of the best cows and bulls was based on phenotypic records for diseases, lactation performance, fertility, growth rate, and temperament. Genetic parameters and evaluations of these traits have not been calculated before. However, to develop a sustainable breeding programme, it is important to estimate the variance components and genetic parameters, such as heritability and repeatability for production and fertility traits. Variance components and genetic parameters are key factors for prediction of selection response for a particular breeding programme. The availability of estimated breeding values (EBV) for production and fertility traits in Mpwapwa cattle population will help develop optimal selection and mating strategies of superior cows and bulls in an optimal breeding programme.

The objective of this study was therefore to estimate genetic parameters and breeding values of individual animals, and determine the genetic progress that has been achieved over the past four decades in Mpwapwa breed through nucleus breeding programme.

Materials and Methods

Data for the present study were acquired from the Tanzania Livestock Research Institute, Mpwapa, Tanzania. The research institute farm is located at 1,100 m above sea level in the semi-arid zone of central Tanzania. The average annual rainfall at the institute is 660 mm, of which more than 90% falls between December and April. The mean daily temperature is 26 °C, with the minimum temperature of 13.8 °C in August and a maximum of 30.2 °C in November. The production seasons are divided into the wet (December to June) and dry season (July to November). The farm is dominated by natural pastures consisting mainly of *Hyparrhenia spp.*, *Brachiaria brizantha*, *Cynodon dactylon*, *Chloris gayana*, *Cenchrus ciliaris*, *Heteropogon contortus*, and *Panicum maximum*. These are considered suitable forage grasses. However, their distribution and quantity vary between the two seasons of the year (Greenway, 1933; Katyega, 1987; Bwire & Wiktorsson, 2003). Before 1998, the average herd size was greater than 1,000 animals (Syrstad, 1990). However, since 1999, the herd size has remained below 1,000 animals (Bwire *et al.*, 2005; ILRI, 2009). All cows were grazed on natural pastures from 7:30 am to 3:00 pm and received a certain amount of concentrates, composed of maize bran, minerals and sunflower or cotton seed cake during milking. Livestock management included control of parasites and diseases through dipping, deworming, and vaccination. Cows with less than 1,000 kg lactation milk and 84 days in LL were culled from the herd. Cows with milk yield above 2,000 kg were considered elite. The restricted suckling method was applied in which three teats were milked and one was left for the calf to suckle until weaning at the age 90 days. After weaning, all teats were milked with a deliberate drying off at 305 days for cows with longer LL (Bwire *et al.*, 2005).

A total of 3,700 total lactation milk yield records for cows calving from 1967 to 2012 were retrieved. Data for milk yield were recorded daily. The individual cow record card consisted of birth date, calving date, parity, LMY, and LL. Reproduction traits, such as AFC and calving interval (CI), were calculated using birth dates and calving dates, respectively. Production traits

Chapter 3: Genetic progress in centrally based breeding programmes

included total LMY, 305-day LMY (305LMY), and LL. Total lactation yield was adjusted to 305 days to account for cows that had been sold or had died before completing the lactation. The dataset consisted of the Mpwapwa crossline (F1) of 56% *Bos taurus*, first backcross (R1) of 34% *Bos taurus*, inter-se of 34% *Bos taurus*, Mpwapwa crosses with Boran and Sahiwal, and pure Mpwapwa with 8% *Bos taurus*. Only data for cows with breed composition of 8% *Bos taurus* that were regarded as pure Mpwapwa breed were retained for analysis. Cows with a LL of less than 100 days were excluded in the analysis. Each cow used for data analysis had at least one parent of known pedigree information. After data editing, 1,003 lactation records from 385 Mpwapwa cows were retained for analysis.

Statistical Analysis System (SAS, 2011, version 9.3) software was used in sorting, summarizing, merging, creating new variables, and combining datasets. The restricted maximum likelihood (REML) procedure was used to estimate (co)variance components for production and reproduction traits with the ASReml version 3 software program (Gilmour *et al.*, 2009). The following repeatability animal model was fitted for milk yield, LL, and CI. For AFC no permanent environmental effect was fitted as there was always only a single record per animal:

$$y = X\beta + Za + Wpe + e$$

Where: y is a vector of phenotypic observation of traits

β is vector of fixed effects

a is a vector of additive genetic random effects

pe is a vector of permanent environment of cow random effects

e is the vector of random error effects

X, Z, W are the respective incidence matrices

Fixed effects included year-season of calving, parity number (except for AFC), and LL (for LMY only).

It was assumed that the expectation (E) of y (Ey) = $X\beta$; $E(a) = 0$ and $E(e) = 0$. the $\text{var}(a) = A\sigma_a^2 = G$, $\text{var}(pe) = I\sigma_{pe}^2$ and $\text{var}(e) = I\sigma_e^2 = R$; hence, $\text{var}(y) = ZAZ'\sigma_a^2 + Wl\sigma_{pe}^2W' + R$, with A being the numerator relationship matrix between the animals of the study and A^{-1} is the inverse of A (Henderson, 1973; Mrode & Thompson, 2005). Heritability (h^2) was calculated as:

$$h^2 = \sigma_a^2 / (\sigma_a^2 + \sigma_{pe}^2 + \sigma_e^2)$$

and repeatability (r) was calculated as

$$r = (\sigma_a^2 + \sigma_{pe}^2) / (\sigma_a^2 + \sigma_{pe}^2 + \sigma_e^2).$$

Solutions of the animal effect constituted individual animal EBVs. Phenotypic trend was obtained by plotting a mean of performance of a trait by year of calving, while the genetic trends were derived with the mean yearly EBVs.

A series of bivariate analyses based on the above model were also conducted to estimate phenotypic and genetic correlations among the traits.

Results and Discussion

A summary of descriptive statistics for production and reproduction traits evaluated in this study are presented in Table 3.1.

Table 3.1 Means and standard deviations for production and reproduction traits of Mpwapwa cows

Parameters	N	Mean ± SD	95% Confidence Interval		Min	Max	CV (%)
			Lower	Upper			
Milk production parameters							
LMY (kg)	1,003	1,480.0 ± 506.3	1,448.7	1,511.3	805.0	3,481.0	34.2
305 LMY (kg)	1,013	1,686.0 ± 578.6	1,650.2	1,721.8	810.5	4,770.43	34.2
LL (days	1,013	271.4 ± 44.7	269.1	274.2	102.0	305.0	16.5
Reproduction parameters							
CI (days)	467	493.1 ± 130.7	481.3	505.0	351.0	899	26.5
AFC (months)	527	32.0 ± 7.1	31.4	32.6	28.0	62.0	22.2
Min: minimum, Max: maximum, CV: coefficient of variation							

There was large variation among cows for LMY (34%) and CI (26%). The current lactation yield was lower than that reported by Mchau and Syrstad (1991) (1,519–1,560 kg) and Rushalaza & Kasonta (1993), but similar to the previous on-station estimate of 1,446.4 kg (Das *et al.*, 1999). Owing to the lack of on-farm performance records for the Mpwapwa breed, it was difficult to compare current on-station lactation yield with on-farm performance. The differences observed in LMY of Mpwapwa from various studies may be due to variations in environment conditions and levels of management of the animals in different years. The mean milk yield observed in the present study was within the range of 1,000 to 2,477 kg of lactation milk yield reported for improved zebu in the tropics (Cunningham & Syrstad, 1987) and crossbred dairy cows for smallholder dairy farmers under intensive production systems in Tanzania (Chenyambuga & Mseleko, 2009; Msanga *et al.*, 2000).

The overall mean LL for all lactations was 271.4 ± 44.7 days. The number of days in milk was generally moderate compared to the standard 305 days. The LL for the current study was higher than for previous on-station studies (228 days) (Das *et al.*, 1999) and lower than for on-farm studies (300 days) (Rushalaza & Kasonta, 1993). However, the LL observed in the present study was lower than the 278.7 to 326 days reported for crossbred cows in smallholder dairy farms in sub-Saharan Africa (Banda, 1996; Chenyambuga & Mseleko, 2009; Gebreyohannes *et al.*, 2013). A number of studies in sub-Saharan Africa have shown that an increase in number of days in milk is associated with an increase in LMY (Ngongoni *et al.*, 2006; Chenyambuga & Mseleko, 2009). Therefore, the low mean LL in the current study can be associated with low LMY of the Mpwapwa breed compared with other crossbred dairy cows.

The long mean CI of 493.1 days observed in this study is comparable with 402 to 480.4 days reported by previous studies in Tanzania (Asimwe & Kifaro, 2007; Swai *et al.*, 2007; Chenyambuga & Mseleko, 2009). The current study indicated that CI (493.1 ± 130.7) was almost twice that of LL (271.4 ± 44.7 days), implying that there was a long period when cows were not lactating

or pregnant and, therefore, not productive. Bozworth *et al.* (1971) associated longer CI with inefficiency in heat detection, conception rate, and reproductive health in larger farms.

About 95% of the heifers calved at an age between 31.4 and 32.6 months. The AFC of the present study was within the range of 31.3 to 36.6 months of AFC for tropical crossbred heifers (Asimwe & Kifaro 2007; Yifat *et al.*, 2009) and dual-purpose synthetic breeds (Galukande *et al.*, 2013). Improvement in the production environment may enhance the growth rate and maturity of the heifers, and hence reduce AFC. Reduced AFC has been associated with increased productivity per herd life and reduced cost of rearing heifers (Teke & Murat 2013). The differences in milk production and LL for cows calving in the wet and dry seasons were not statistically significant. The non-significant effect of the season on the production variables may be attributed to management, mainly feeding management of milking cows, which allows them to maintain physiological balance and react positively to seasonal variations. However, the year of calving significantly affected production traits. The effect of year of calving may be associated with changes in management systems and climatic factors over the years.

The mean yearly LMY, 305LMY and LL showed a general declining trend (Figure 3.1) with some periodical increase and decrease throughout the study period. Cows calving between 1973 and 1984 had better performance than cows that calved between 1985 and 2000. The increase in milk yield from 1973 to 1984 could be explained by active breeding activities (Syrstad, 1990; Bwire *et al.*, 2005). It was during this period that the breeding target for beef production was realized. However, the target of 2,300 kg milk per lactation of 305 days was not reached. The declining milk production trend between 1985 and 1993 could be due to limited funding for research and production services because of the structural adjustment policy of the International Monetary Fund and World Bank to ensure debt repayment and economic restructuring of developing nations. As a result, most countries in Africa, including Tanzania, reduced their spending on health, education, and development activities,

including research. During this period, most of the parastatal farms were reduced in size or privatized (Heidhues & Obare, 2011). This led to a decline in the number of breeding cows, followed by reduced selection pressure for best cows and bulls. The failure of public expenditure cut policies led the government and other donors to revive previous efforts to expand parastatal sectors. As result, the upward trend from 1994 could be explained by active support of the government on breed multiplication through projects such as Tanzania Agricultural Research Project Phase II (TARPII) (Nankani *et al.*, 2004) and Agricultural Sector Development Programme (URT, 2006). However, it is apparent from this study that the level of milk production overall has not increased for the past 40 years. The current management strategy needs to be revised to attain the desired breeding goal of the 2,300 kg of milk per lactation. The Mpwapwa breed, like any other crossbred dairy animals in the tropics, is vulnerable to disease and lack of feed resources. Additional management of the animals in terms of general husbandry and feeding strategies is required. In addition, the current genetic improvement programme needs to adopt new technologies of feeding, reproduction and genotyping to improve the environment, fertility and selection of cows and bulls with an acceptable range of breed composition.

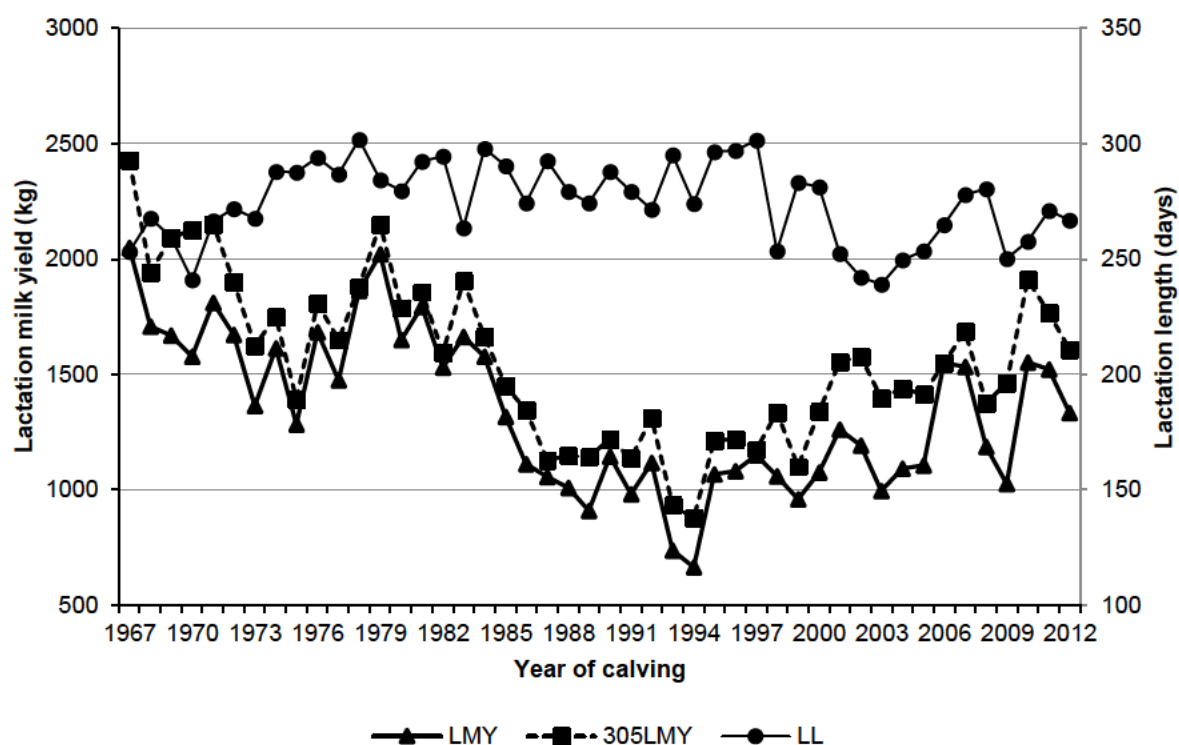


Figure 3.1 Phenotypic trend of yearly mean lactation milk yield, 305-day lactation milk yield and lactation length for Mpwapwa breed

Figure 3.2 shows an increase in AFC from 1967 to 2012, while the CI interval remained almost constant. Increase in AFC over time in the present study could be attributed to management factors, leading to a poor conception rate of heifers that tend to remain in herd for a long time. The breeding protocol for Mpwapwa requires heifers that weigh less than 200 kg at the age of two to be culled. However, this has not been practised owing to the small number of females that were available for breeding (Bwire *et al.*, 2005). As a result, heifers that did not meet the mating criterion were retained for the next breeding season. The CI has remained between 400 to 500 days which is similar to other dairy cows in sub-Saharan Africa reported in previous studies (Chagunda *et al.*, 2004; Tadese *et al.*, 2010).

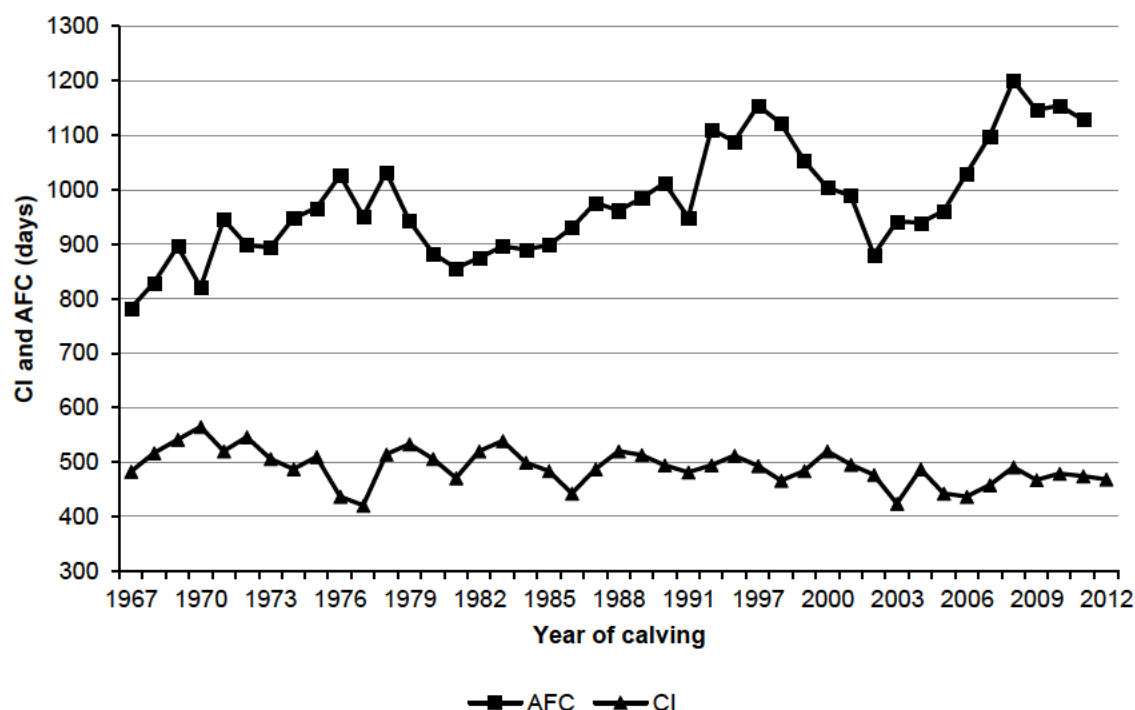


Figure 3.2 Phenotypic trend of yearly mean age at first calving and calving interval for Mpwapwa breed

AFC: age at first calving; CI: calving interval.

The genetic parameter estimates for production and fertility traits are presented in Table 3.2. With the exception of LL and AFC heritability, estimates were statistically greater than zero ($P < 0.05$). Heritability estimates for milk production traits were within the range of previous estimates for improved zebu and crossbred cows in sub-Saharan Africa (Mwatawala et al., 2002) and significantly higher than for tropical dairy populations reported by Demeke et al., 2004 and Ilatsia et al., 2007. Heritability estimates for LMY and 305LMY were moderately high, which implies that the trait could be used for the genetic improvement of the breed via selection. Higher estimates of heritability for LMY and 305dMY among different studies may be caused by different estimation methods, amount of data, environmental interactions and unpredictable genetic effects. Therefore, estimates of heritability from the current study should be referred to the Mpwapwa synthetic population and not to the crossbred population in sub-Saharan Africa. The heritability estimate of $0.13 \pm$

0.11 for AFC was higher than for Sahiwal cattle and crossbred cows (Mwatawala *et al.*, 2002; Amimo *et al.*, 2006; Ilatsia *et al.*, 2007), but lower than for purebred Holstein-Friesians in Malawi (0.2) (Chagunda *et al.*, 2004) and Kenya (0.38) (Ojango & Pollott, 2001). Heritability value for CI was low (0.10), which is similar to improved zebu and crossbreds (Mwatawala *et al.*, 2002; Ilatsia *et al.*, 2007), but lower than Kenyan Holstein Friesians (Ojango & Pollott, 2001).

Heritability for AFC and CI is generally considered low, which suggests that these traits are affected by environment and other farm management policies more than additive gene action. The higher standard error for heritability estimates for AFC could be due to the small number of records, data structure, and historical background of the development of the breed. Therefore, more records may be required for further evaluation of the traits. However, it is possible to reduce CI and AFC by improving feeding and fertility management of the animals. Improved feeding management and culling of heifers with low body weight at the age of 72 weeks could reduce the age at first mating because of improved growth and early maturity. On the other hand, heifers and cows that are well fed are likely to undergo normal cyclic behaviour and therefore to improve both AFC and CI. Studies in temperate countries have suggested the possibility of selection for reduced CI by using other genetically correlated traits such as body condition score and milk progesterone (Dal Zotto *et al.*, 2007; Nyman *et al.*, 2014). A decrease in AFC and CI would reduce the cost for herd replacement and maximize the longevity and the productive life of a cow. Therefore, in the current breeding scheme, genetic gain for reproductive traits could be improved by culling poor performing animals and improving environment and management strategies.

Repeatability estimates for production traits ranged from moderate for LL (0.27) to high for LMY and 305LMY (0.62-0.70). The estimates for LMY and 305LMY were higher compared with previous studies of improved zebu in low-input production systems in sub-Saharan Africa (Ilatsia *et al.*, 2007; Badri *et al.*, 2011). Conversely, the repeatability estimates for LL was moderate, but

consistent with other studies of improved zebu in the tropics (Ilatsia *et al.*, 2007; Badri *et al.*, 2011; Santos *et al.*, 2013). The repeatability estimates for production traits indicate that selection of the best cows to be kept in the herd for production could be done with some degree of precision based on estimates for LMY, 305LMY and LL of the cows.

The repeatability for CI (0.10) was low, which is consistent with other previous studies for crossbred cows in sub-Saharan Africa (Chagunda *et al.*, 2004; Ilatsia *et al.*, 2007). The low genetic parameter estimates could be owing to the small number of records for CI used in this study. Furthermore, the repeatability value was the same as heritability because of no permanent environment variance, suggesting that researchers may not predict the future CI of the same cow from her current records any better than predict the CI of her progeny.

Table 3.2 Estimates of additive genetic variance (σ^2), variance due to permanent (σ^2_{pe}), phenotypic variance (σ^2_p), residual variance (σ^2_e), heritability ($h^2 \pm SE$) and repeatability ($r \pm SE$) for production and reproduction traits for Mpwapwa cows

Parameter	LMY (kg)	305LMY (kg)	LL (days)	CI (days)	AFC (Month)
σ^2_a	78,920.0	169,100.0	242.99.0	1,6524.0	2,248.20
σ^2_p	242,790.0	382,190.0	1,854.5.0	1,6877.0	17,549.0
σ^2_{pe}	73,070.97	95,595.30	261.67.0	0.00005.0	_____
σ^2_e	90,795.30	117,486.0	1,349.81.0	15,224.20	15,300.60
h^2	0.33 \pm 0.11	0.44 \pm 0.04	0.13 \pm 0.17.0	0.10 \pm 0.05	0.13 \pm 0.11
r	0.62 \pm 0.04	0.70 \pm 0.03	0.27 \pm 0.06	0.10 \pm 0.05	_____

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Phenotypic and genetic correlations for production and reproduction traits are presented in Table 3.3.

Table 3.3 Phenotypic (below the diagonal) and genetic (above the diagonal) correlations among production and reproduction traits

Trait	305LMY	LMY	CI	AFC
305LMY		$0.87 \pm 0.02^*$	$-0.06 \pm 0.009^*$	0.0
LMY	$0.82 \pm 0.01^*$		0.15 ± 0.11	0.0
CI	$-0.01 \pm 0.001^*$	0.06 ± 0.05		0.0
AFC	-0.11 ± 0.0	-0.12 ± 0.0	-0.10 ± 0.0	

*Correlations between parameters are significantly different from zero

The phenotypic (0.82) and genetic (0.87) correlations between 305LMY and LMY were high, positive, and significantly different from zero. Phenotypic and genetic correlations between 305LMY and CI traits were low and closer to zero, but significant from zero (-0.01 and -0.06). The low phenotypic correlation between 305LMY and CI traits is consistent with other studies in the tropics for purebred and crossbred dairy cows (Syrstad, 1993; Adeoye & Ogundipe, 2011). However, Ilatsia *et al.* (2007) and Rehman *et al.* (2008) reported higher and positive phenotypic correlation between lactation milk yield and CI for Sahiwal cows in the tropics. The genetic correlation between production and reproduction traits from the current study was within the range of -0.64 -0.91 reported for improved zebu and crossbred dairy cows in the tropics (Ojango & Pollott, 2001; Rehman *et al.*, 2008; Zeleke *et al.*, 2016). A low genetic correlation between 305LMY and CI indicates a weak genetic and physiological relationship between the traits. A low genetic relationship indicates a necessity for improvement of reproductive management and further investigation of environmental factors controlling the traits. Phenotypic and genetic correlations between production and reproduction traits were low, suggesting that selection for one trait group will not affect the other. Therefore,

there is not sufficient evidence that selection based on reproductive traits would lead to increased milk yield. However, selection based on 305LMY may lead to higher response in milk production.

The calculated rate of inbreeding depression was 0.24% per generation based on the data used. This might not be a true representative value of the population because of the small pedigree information used in this particular study. The true picture would have been attained if all animals involved in a breeding programme had been recorded. However, the current study showed lower inbreeding depression. This could be because of factors such as pedigree size and mating strategies applied at the farm. Therefore, there is no evidence to conclude that the declining trend in production and fertility traits is associated with inbreeding depression.

Average EBV for 305LMY of individual animals by year of birth are presented in Figures 3a & 3b for sires and cows, respectively. The genetic trend for both sire and cow EBV for milk production was negative, which indicates a reduction in the genetic propensity of the animals to produce milk over time. The overall rates of EBV change were -3.0kg/year for sires and -1.2kg/year for cows. Various factors might have led to these trends, including intensive selection of cows and bulls for high milk yield between 1968s and 1985. The declining trend of genetic progress in 1985, followed by an increase in 1994, can be explained by changing policies. The adoption of public expenditure cuts in 1980s affected both production and social services such as research and extension (Heidhues & Obare, 2011). However, the positive genetic trend since 1994 may be explained by government strengthening research institutions and extension services (URT, 2006). The overall negative genetic progress may be linked to longer generation intervals as a result of delayed age at first calving and longer CIs. Similar trends in EBV for milk yield have been observed in multi-breed populations of dairy cattle in Ethiopia (Gebreyohannes *et al.*, 2013). Studies on Brazilian improved zebu such as Gry and Guzerat (Verneque *et al.*, 1996, Peixoto *et al.*, 2006) have shown that positive genetic progress for milk yield can be achieved in a tropical

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environment when appropriate selection strategies are in place. For example, Peixoto *et al.* (2006) reported an annual genetic gain of 7.0 kg per year for the Guzarat breed in Brazil. Selection and culling processes practised to date have been suboptimal because parents were selected based on their phenotypic performance rather than EBV.

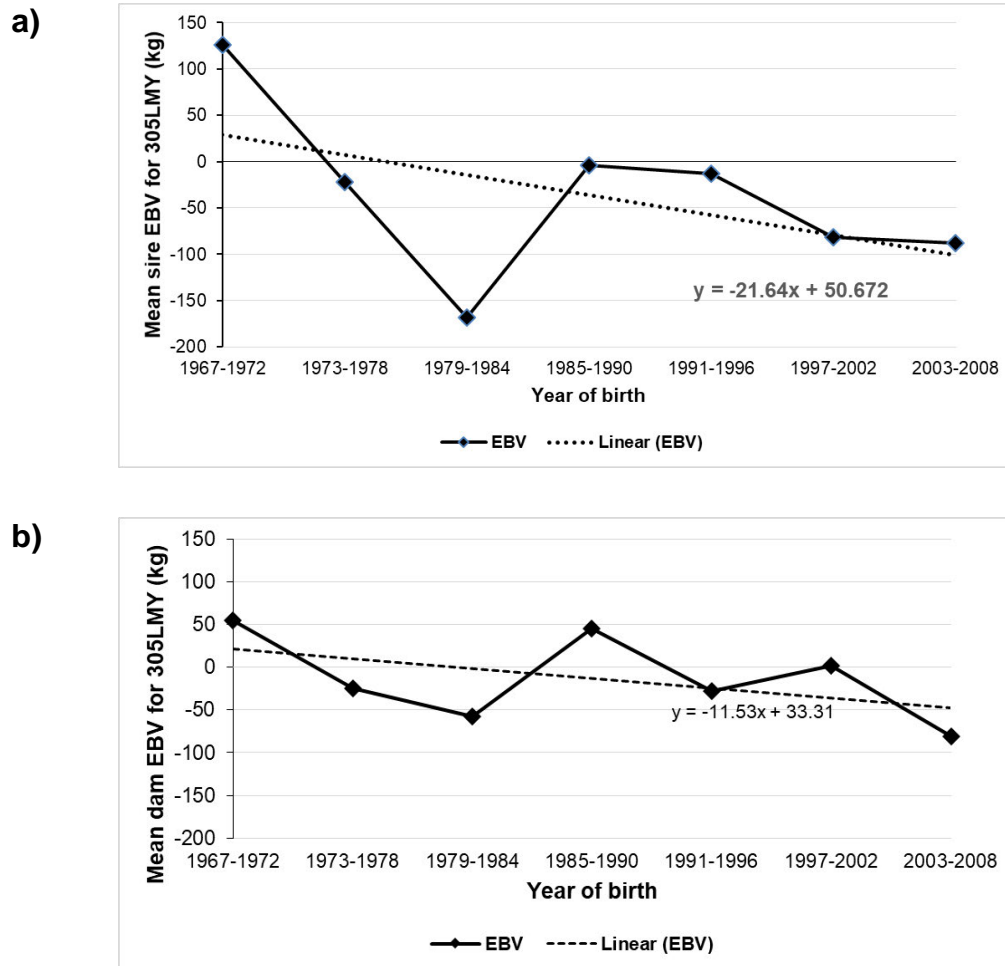


Figure 3.3 Trend in estimated breeding values for 305 days' lactation milk yield by year of birth for a) sire and b) cow

EBV: estimated breeding values; 305LMY: 305-day lactation milk yield.

The genetic trend for LL was negative, which indicates a decrease of - 0.05 days per year (Figure 3.4). The decrease in LL attributed to a reduced 305LMY. Studies in the tropics have reported a positive phenotypic and genetic correlation for LMY and LL for improved zebu (Dahlin *et al.*, 1998),

which indicates that selection for milk yield, accompanied by improved management, could improve LL. In the tropics, LL is used as a measure of persistency in milk production as result of climatic challenges, which is contrary to temperate dairy breeds where LL is used as a measure of milk yield, and a decrease in milk production is caused mainly by the advanced stage of gestation (Syrstad, 1990). In tropics, few cows can reach the standard LL of 305 days. The main reason for shorter LL is that cows are dried off because of poor milk let down. On the other hand, LL is a heritable trait that can be used as a marker for the resilience of dairy cattle in tropics.

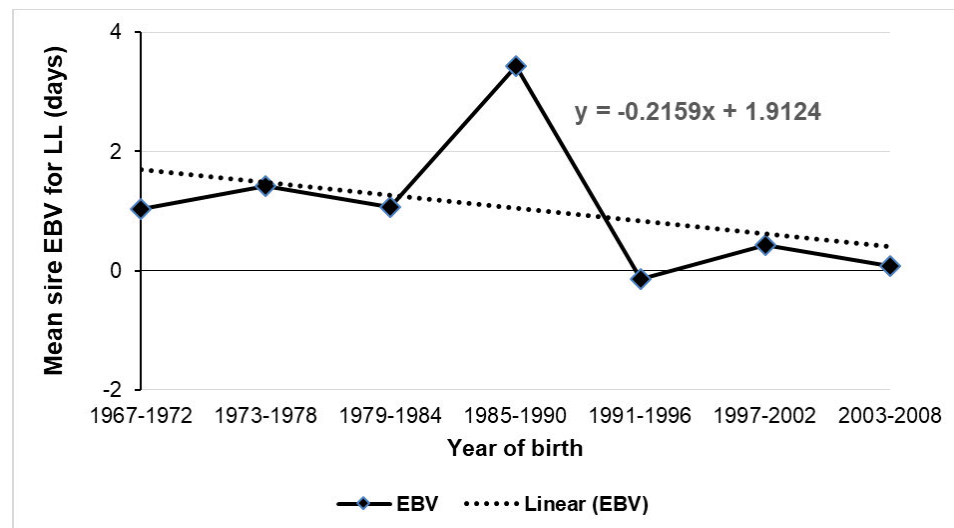


Figure 3.4 Genetic trend of sire estimated breeding values for lactation length (days) of the Mpwapwa breed

EBV: estimated breeding values; LL: lactation length.

The genetic trends of sires for CI and AFC have remained close to zero (Figure 3.5a & 3.5b) over time. Since the Mpwapwa breeding scheme emphasizes milk and meat yield, reproductive traits could be improved by selecting heifers with higher growth rates and by closer monitoring and culling of cows with poor fertility. These two traits have low heritability. Therefore, environmental effects such as feed, care, and disease resistance play a significant role in their improvement.

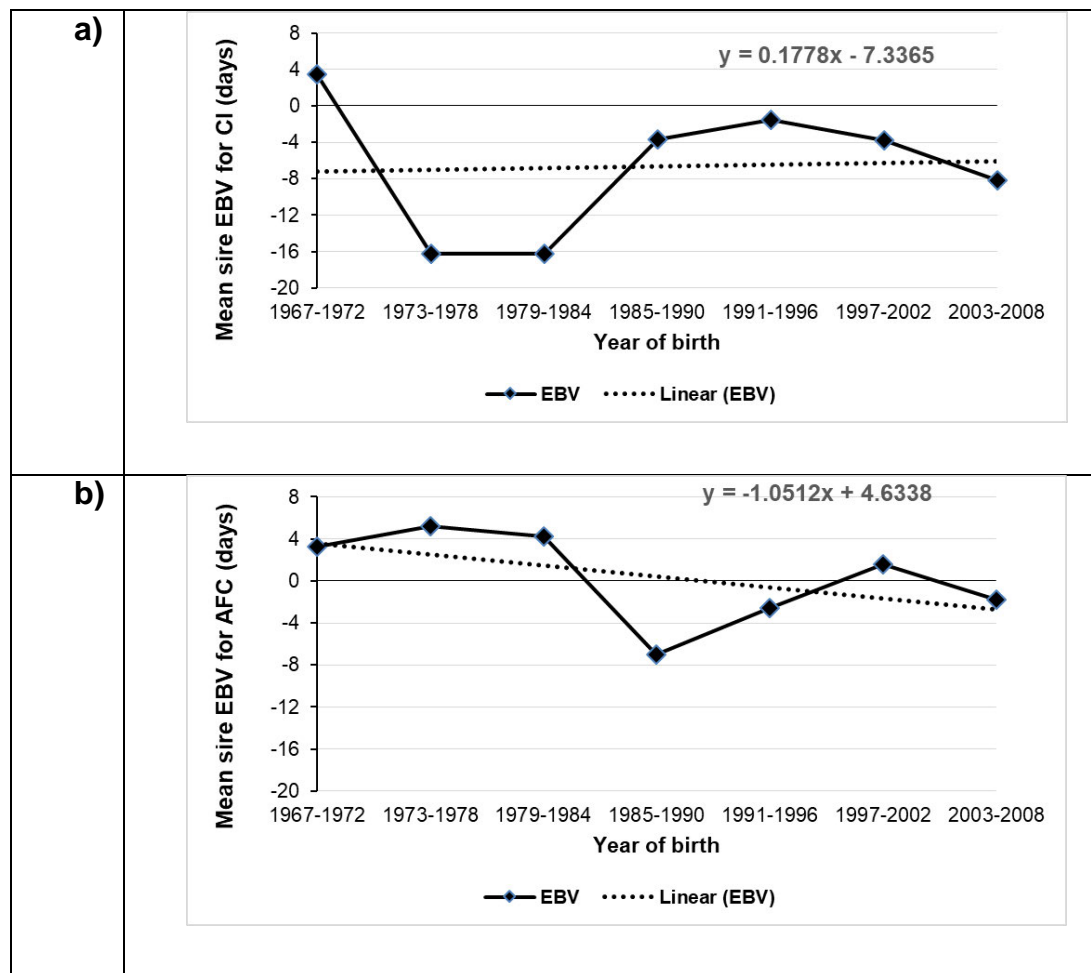


Figure 3.5 Trend in for a) calving interval and b) age at first calving in days of Mpwapwa cows

EBV: estimated breeding values; CI: calving interval; AFC: age at first calving

The distribution of sire EBV for 305LMY ranged from -600 to +900 kg of milk per lactation (Figure 3.6), while for LL it ranged from -8.3 to 15.6 days. On the one hand, 37 out of 78 sires had favourable (0–900kg) EBV for milk yield, suggesting the possibility of selecting sires, leading to positive genetic gain. On the other hand, 53 bulls had EBV for LL ranging from 0 to +10 days, indicating a wide choice of bulls for favourable increase in LL, if this ever becomes part of the breeding goal.

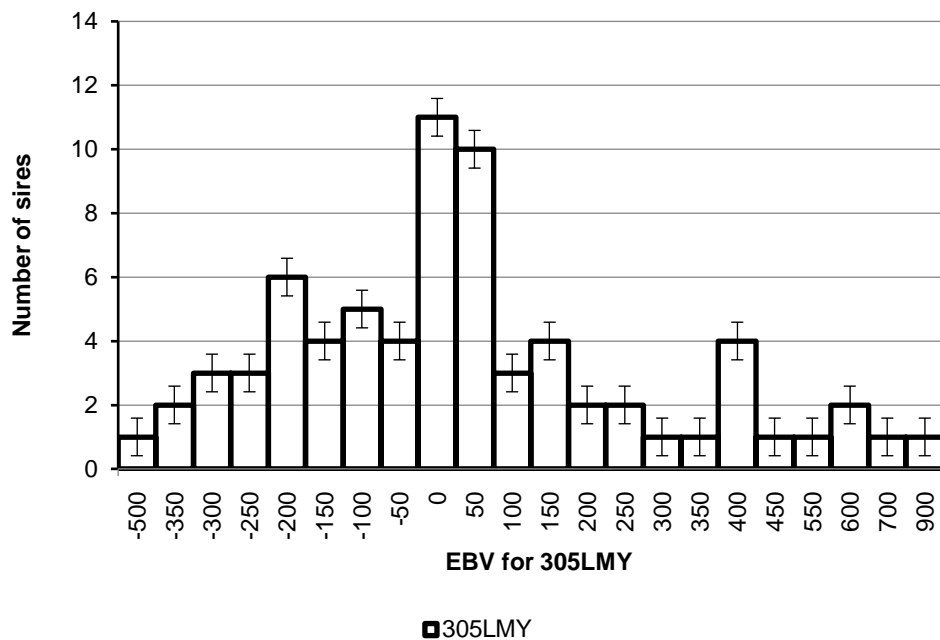


Figure 3.6 Distribution of sire estimated breeding values for 305-day lactation milk yield of Mpwapwa breed with error bars representing standard errors of means

EBV: estimated breeding values; 305LMY: 305-day lactation milk yield.

Estimated individual sire breeding values for AFC and CI varied from -50 to +150 days and -45 to +50 days, respectively. The observed variation in EBV between animals in the present study supports the feasibility of selecting cows and bulls as parents in a breeding programme over multiple years. Although the two traits were found to be low in heritability, individual bulls with negative EBV for CI and AFC may be selected as potential sires in the breeding programme. Improvement of fertility traits is necessary for a successful dairy enterprise, since regular calving at a minimal interval is essential for constant milk production all year round. Long CIs owing to genetic and non-genetic factors would lead to low productivity and slow genetic progress over time.

Conclusions

Phenotypic and genetic correlations between 305LMY and LMY were high, positive, and significantly different from zero. This suggests that 305LMY

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could be used an important selection criterion for increased milk yield. The genetic correlation between 305LMY and CI was low, suggesting that selection for one trait would not affect the other. All these traits of the Mpwapwa breed have shown an overall decline in phenotypic and genetic progress over the past four decades. This could be owing to unsystematic breeding policies and weak monitoring of the genetic progress. Thus, systematic planning of the genetic improvement programme of the breeding scheme is essential to avoid a declining genetic trend for production and reproduction traits. A favourable trend could be established in this programme and transferred to smallholder dairy production systems. Further understanding of the performance of the breed in a smallholder dairy production system is required for an effective and sustainable genetic improvement programme.

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Authors' Contributions

ARC conducted the research during his PhD studies and was responsible for drafting, analysing data and submitting the manuscript. MGGC, GB, AP and

DMK coordinated the study, critically analysed and interpreted the results and participated in the manuscript development.

Conflict of Interest Declaration

The authors of this paper declare that there is no conflict of interest. They confirm that the order of listing authors has been agreed by them and the manuscript has been read and approved by all authors.

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3.3 Chapter conclusion

This chapter address a case study of on-station dairy cattle breeding strategies for low and medium input production systems. Over the years, some of the Mpwapwa heifers and bulls have been sold or offered for breeding purposes to smallholder and large-scale dairy farms across Tanzania with a key emphasis on increasing milk and beef productivity. As in many other developing countries, no substantial genetic progress has been achieved over the last 40 years. The breeding target of 2,300kg of milk per lactation set by researchers has not been met and there is a decline in genetic progress for milk yield over time. From the study, we can conclude that centrally based (top-down) breeding strategy has not made a significant contribution to the genetic progress of the breed. Generally, sustainability of breeding programmes largely depends on farmer's interests and willingness to adopt a breeding strategy. Therefore, greater emphasis should be placed on including farmers' views in the breeding programmes. In order to bridge the gap between researchers and smallholder dairy farmer breeding goal interests, the next chapter investigates farmer-driven breeding goals and the relative emphasis of traits identified by farmers in different agro-ecological zones and production systems.

Chapter 4 Farmer-preferred traits in smallholder dairy farming systems in Tanzania

4.1 Chapter introduction

A breeding goal is broadly defined as the direction of genetic improvement of a breeding programme driven by the underlying production system. Defining a breeding goal is an important initial step of implementing a genetic improvement programme in any production system. A well-defined breeding goal will provide guidance and lead to an optimal genetic progress of the breeding programme, whilst inaccurate definition may lead to declines both in economic and biological progress. At present, the objectives of keeping dairy cattle in smallholder production systems in Sub-Saharan Africa are changing to higher productivity. However, there is not sufficient information on traits of economic and social importance for dairy cattle in smallholder dairy farmers, which would form the basis for genetic improvement programmes for increased dairy productivity. This chapter investigates the dairy breeding goals set by smallholder farmers themselves, including the relative priority of animal traits for sustainable dairy production in Sub-Saharan Africa, using Tanzania as a case study. The study has highlighted a list of important traits considered by farmers in the breeding goal and quantified their relative importance, thereby addressing the third objective of the thesis. The main body of chapter consists of a scientific publication in the *Tropical Animal Health and Production Journal* as:

Chawala, A. R., Banos, G., Peters, A., & Chagunda, M. G. G. (2019). Farmer-preferred traits in smallholder dairy farming systems in Tanzania. *Tropical Animal Health and Production*, 51(6), 1337–1344. <https://doi.org/10.1007/s11250-018-01796-9>.

The PhD candidate conducted all the work related to this chapter including developing research question, designing surveys, data analysis and paper writing. The study was conducted under guidance from his supervisors (manuscript co-authors).

4.2 Manuscript

Farmer-preferred traits in smallholder dairy farming systems in Tanzania

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Abstract

Decisions of breeding schemes in many countries in sub-Saharan Africa tend to be either government or project driven, with a focus on upgrading local breeds. However, there is scant information on the individual animal traits that smallholder farmers prefer. The aim of this study was to examine farmers' preferences of dairy cattle traits using discrete choice experiment methodology. The study was conducted through visits to 555 randomly selected dairy farms in the sub-humid Eastern coast and temperate Southern

Chapter 4: Farmer preferred traits in smallholder dairy farming systems

highlands of Tanzania. Choices of animal traits were presented to farmers who were asked to evaluate choice alternatives based on attribute levels and finally select the alternative with the highest utility. The choice experiment data were analysed using a conditional logit model. Coefficients for milk yield, fertility, feed requirement, temperament and diseases resistance were overall statistically significant ($p < 0.05$). In order of perceived importance, farmers were willing to keep a cow with high milk yield (coefficient = 1.43 ± 0.059), good fertility (0.85 ± 0.050), easy temperament (0.76 ± 0.066), low feed requirement (-0.56 ± 0.092) and enhanced tropical disease resistance (0.48 ± 0.048). The purchase price coefficient was negative (-0.001 ± 0.0003), indicating that farmers would prefer improved dairy cattle at affordable prices. Farmers' preferred traits were influenced by agro-ecological zone and type of production system (extensive vs intensive). The study provides an opportunity for breeding programme designers to take farmers' preferred dairy traits into serious consideration.

Keywords: *Dairy traits, Trait preference, Breeding goal, Choice experiment*

Introduction

Smallholder dairy farming, characterised by small herds of 2-3 milking cows, provides a livelihood for more than 150 million farm households worldwide (FAO 2010; DGEA 2015). The majority of smallholder farmers are found in developing countries. In Tanzania, smallholder dairy farming has rapidly developed in the past three decades, mainly due to successful role in poverty alleviation and bridging the gap to increasing demand for milk and milk products. The National dairy cattle herd includes the traditional sector that contributes 70% of the total milk produced, while the remaining amount is produced by the smallholder dairy farmers (Njombe et al. 2011). Studies in dairy marketing shows that 90% of the milk produced in the traditional sector is consumed at household level and only 10% was marketed. This is contrary

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to smallholder dairy farming where 70% of milk produced was marketed and 30% was consumed at home (Njombe et al. 2011; Katjiuongua and Neglen 2014). Total milk production has increased at a rate of 2.8% per year over the past 20 years as a result of growth in the cattle population, rather than an increase in productivity per cow, reflecting a rather inefficient milk production system (FAO 2010; Nell et al. 2014; URT 2016). Previous studies have described the mismatch between the genotypes used and the production environment they are kept in as a major cause of poor productivity in the tropics (Mwacharo et al. 2008; Philipsson et al. 2011).

The vision of the Tanzanian livestock industry is to increase animal productivity and commercialise the livestock sector to ensure improved household food security and income (URT 2006). However, in Tanzania, as in most countries in Sub-Saharan Africa, active participation of smallholder dairy farmers in designing breeding programmes has received little attention (Bebe et al. 2003; Duguma and Janssens 2016). Hence, there is limited information on how farmers contribute to developing and improving the local dairy industry. The International Livestock Research Institute has recently conducted participatory studies - mainly surveys in smallholder dairy production systems - as part of various projects, such as Dairy Genetics East Africa, Tanzania Dairy Genetics, East Africa Dairy Development and More Milk-IT, to identify the important traits that farmers consider when selecting dairy cattle (DGEA 2015). These studies have been mainly based on qualitative research methods, which are limited in revealing trade-offs between traits of interest. Quantitative methods of eliciting preferences such as best-worst scaling and discrete choice experiments have not been used so far in studies aiming to support farmers' decisions for selecting best cows in smallholder dairy production systems.

Duguma et al. (2010) and Ndumu et al. (2008) suggested the use of a combination of survey, ranking and choice experiment methods when identifying traits for selection. In trait preference ranking studies, surveys and trait ranking methods are used to collect information at an early stage, with the

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aim of obtaining a general picture of the list of traits to be considered in a breeding objective. The choice experiment method has been widely used for quantifying farmers' preference traits for various livestock species, including cattle (Ndumu et al. 2008; Wurzinger et al. 2006), sheep (Ragkos and Abas 2015) and pigs (Roessler et al. 2008). The method quantifies qualitative data to calculate the strength of the preferences and trade-offs, and the probability that attributes will become more widespread. Additionally, this method surpasses both surveys and ranking methods in terms of the ability to elicit preferences and reveal trade-offs among attributes. However, this method has not been used yet to establish the relative importance of farmer preferred dairy traits in Tanzania.

The aim of the present study was to determine the most important traits preferred by farmers in smallholder dairy farming systems using both qualitative and quantitative methods. The specific objectives were to: 1) determine farmers' preferred dairy traits that could influence the choice of dairy cows; 2) quantify how dairy farmers evaluate cow traits and consider trade-offs between different attributes in the preferred traits; 3) examine differences in farmers' dairy trait preferences between agro-ecological zones and production systems of Tanzania.

Materials and Methods

Study areas and survey design

The study was conducted in two agro-ecological zones in Tanzania; the Southern highlands and the Eastern coast. The Southern highland study sites included the Iringa rural, Makambako and Njombe districts, while the sites on the Eastern coast included the Tanga city, Muheza and Korogwe districts. The Eastern coast zone is situated between latitude 4° to 6°S and longitude 37° to 39°E. The study covered the coast belts and lowland areas with an altitude of 0 to 800 m above sea level. Temperatures range from 26 to 32°C in hot season

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(December to March) and 20 to 28°C temperatures in cool season of the year. The area receives the amount of 800 to 1,400 mm of rainfall a year. The rainfall distribution pattern is bimodal with long and reliable rains starting in February to May and short rain from October to December (URT 1997). In contrast, the Southern highland zone is located at latitude between 7° to 11.5°S, longitude 30° to 38°E and at an altitude of about 400 to over 2,000 m above sea level. The zone receives a reliable unimodal rainfall distribution pattern ranging from 800 to 3,500 mm starting from December to April. The average minimum and maximum temperatures in highland zone are 10.6 °C and 26.5 °C, respectively (Bisanda et al. 1998, URT, 2016). The two zones were selected based on milk production potential and existence of farmer organisations, milk collection and processing infrastructures. Additionally, there is considerable variation between the two zones in terms of rainfall patterns, temperature, landscape and socio-economic activities. Within each region, two production systems were identified: (i) extensive system, characterised by semi or full grazing on natural pastures with limited purchase of inputs, and (ii) intensive system, characterised by zero grazing with increased use of purchased inputs (Ojango et al. 2017). We used a quantitative method (choice experiment) to identify farmers' preferred dairy traits followed by focused group discussions to test and corroborate choice experiment results.

A choice experiment (CE) questionnaire was used to determine how smallholder dairy farmers view cow traits and how they consider trade-offs between different sets of characteristics (Fishburn 1968). A full factorial CE design with six traits and two levels for each trait was created (Table 4.1). Thus, a total of 64 (2^6) combinations of possible choices were available. The final CE design included a total of eight (8) choice sets or questions with three options "Alternative 1", "Alternative 2" and "Alternative 3". Alternatives 1 and 2 included trait combinations for milk yield, fertility, temperament, disease resistance and feed requirement. Alternative 3 corresponded to neither Alternative 1 nor 2. The questionnaire was designed in such a way that each farmer had to respond to a total of eight choice cards.

Table 4.1 Dairy trait and their corresponding levels used in the discrete choice experiment.

Attribute	Description	Levels Definitions	<i>A priori</i> expectation
i. High milk yield	Milk is a source of protein, employment and income for many smallholder dairy farmers. However, there is vast variation in milk yield between genotypes and production systems. For example, as part of the Dairy Genetics East Africa (DGEA) Project, it was found that higher milk production levels were found in cows under intensive (zero grazing) compared to extensive (grazing and semi-grazing) production systems (DGEA 2015).	Two levels of milk yield of 5 and 10 litres/cow/day were chosen, based on the average milk production in semi-intensive and intensive dairy production systems in Tanzania. - Level 1: 5 litre/cow/day accounted for the actual milk production per cow of the majority of smallholder dairy farmers (about 90%) (DGEA 2015). - Level 2: 10 litres /cow/day accounted for the top 10% of the best smallholder dairy farmers (DGEA 2015).	In general, a positive preference for higher milk yield /cow/day was expected
ii. Good fertility	Smallholder dairy farmers are interested in cow fertility to ensure continued milk production on farm. Longer calving interval affects annual milk production and increases labour costs. The reported calving interval of improved dairy cattle in Tanzania ranges between 13-16 months, which is comparable to most countries in sub-Saharan Africa.	Two levels were chosen for cow fertility in smallholder dairy farms. - Level 1: one calf after every 1 to 1.25 years, considered good fertility. - Level 2: 1 calf after every 2 years, considered poor fertility.	In general, a positive preference for cows that produces a calf every year is expected

iii. Animals that best convert of the commonly available feeds into milk	Daily feed requirement is important due to seasonal availability of feeds and under developed pastures on most of the farms (DGEA 2015). This attribute describes the adaptability of cows to utilise commonly available feed resources for growth and milk production. Poor growth rate has an impact on age at first calving, feed costs and can reduce life time milk production.	Two levels were chosen for the ability of the cow to use the available feed resources - Level 1: Smaller body size (low feed requirement) to produce moderate volumes of milk using locally available feed resources - Level 2: Large body size (high feed requirements) to produce high volumes of milk using locally available feed resources	Current breeding strategies are based on increased milk volumes per cow. Therefore, a positive preference for cows with higher milk volumes and hence higher feed requirements was expected.
iv. Temperament	Good temperament is used as criteria for easy handling of cows. During the focused group discussions; temperament was a prominent trait for farmers under semi-grazing systems where animals were taken for grazing or tethered in pasture plots.	Preference for temperament was assessed in two levels. - Level 1: docile cow / easy to care - Level 2: Aggressive cow	- In general, a positive preference for good temperament of cows was expected
v. Animals better adapted to the local production environment.	This attribute includes a range of climatic factors affecting cow productivity. Adaptability to temperature and diseases affects the economic performance of a cow directly through reduced veterinary costs and improved quality of products. For example, in coastal areas, adaptability to hot and humid	Two Levels of adaptability to production environment were chosen based on annual disease incidences and of use of veterinary services:	- In general, a positive preference for low incidence of veterinary service use was expected

	coastal environments such as tolerance to high ambient temperatures and high humidity are essential. In the highlands and medium altitude areas, ability to cope with different disease e.g. tick-borne diseases is important.	<ul style="list-style-type: none"> - Level 1: Animal frequently treated for various diseases treatments (≥ 4 times a year) - Level 2: Animal rarely treated for various diseases (< 4 times a year) 	
vi. Purchase price of cow with the desired traits	The purchase price attribute was based on the current prevailing market price for dairy heifers in Tanzania. For example, as part of the DGEA project in Tanzania, it was reported that purebred animals fetched a higher price than crossbreds. The price range for improved dairy cows in Tanzania ranges between 750,000 - 1,200,000 TZS with an average of 850,000 TZS (DGEA 2015).	<p>Two price levels were included based on current market prices for improved dairy cattle in Tanzania.</p> <ul style="list-style-type: none"> - Level 1: 750,000 TZS - equivalent to £250. This accounted for a lower price for improved dairy cattle Level 2: 1,200,000 - equivalent to £400. This accounted for a higher price for improved dairy cattle. 	Positive preference for reduced animal price was expected

Data collection and statistical analysis

A purposive sample of five wards per district was selected for study based on the prior information on wards participating in data recording scheme under African Dairy Genetic Gains Project (ILRI 2017). In each ward, 15 smallholder dairy farmers were randomly chosen from a list of households that were participating in data recording as part of the African Dairy Genetic Gains project. The minimum sample size required for each zone was calculated by the following equation suggested by Orme, 2010.

$$N \geq 500c / (t \times a)$$

Where, N is the number of respondents, “c” is the largest number levels for any trait, “t” is the number of choice tasks and “a” is the number of alternatives per task. This sample of households was selected from about 2,000 households in the two regions that were participating in data recording as part of the African Dairy Genetic Gains project (ILRI 2017).

A total of 286 and 269 households were selected in Southern highland and Eastern coast, respectively. The number of households sampled in extensive and intensive systems was 131 and 424, respectively, across the two regions. Choices of animal traits were presented to the farmers who were then asked to evaluate choice alternatives based on attribute levels and finally select the alternative with the highest utility.

Data were analysed using the following conditional logit model; the model was applied both within and across agro-ecological regions and production systems:

$$\text{Model: } Pr(\text{Choice}) = \beta_0 + \sum_i \beta_i X_i + \varepsilon_i$$

Where: ***Pr (Choice)*** = probability of choosing a specific trait combination; β_0 = alternative specific constant (intercept); β_i = reference weight for trait *i*; X_i = the level of trait *i*; ε_i = error term.

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Solutions for the β_i values corresponded to estimate coefficients of farmer preferred dairy traits. Higher estimates of the coefficients corresponded to higher emphasis placed on this trait by the farmer.

The goodness of fit of the model was measured by the Likelihood ratio test (ρ^2 = pseudo rho-squared) defined as (McFadden 1977):

$$\rho^2 = 1 - \frac{\text{Log Likelihood of model}}{\text{Log Likelihood of model without predictors}}$$

Marginal willingness to pay (MWTP) for each trait was estimated as follows:

$$\text{MWTP} = -1 * \left(\frac{\beta_i}{\beta_{\text{price}}} \right)$$

where, β_i is the estimated coefficient of trait i , β_{price} is the estimated price coefficient (Roessler et al. 2008, Aizaki 2012). The 95% confidence intervals for MWTP were estimated using a simulation method, as proposed by Krinsky and Robb (1986) with 10,000 replications. The MWTP for traits was calculated by agro-ecological zones to account for variation in farmer's preference traits, climatic factors and milk marketing strategies.

The functions *clogit*, *gofm* and *mwtp* of “survival and support.CEs packages” (Aizaki 2012, Therneau 2015) R (Core Team 2017) software were used to estimate the above coefficients, goodness of fit of the fitted models and MWTP, respectively.

Results

The overall results across both agro-ecological zones and production systems are presented in Table 4.2. Coefficients for animal milk yield, fertility, feed requirement, temperament and disease resistance traits were statistically significant ($p < 0.05$). Results indicate that, overall, farmers were willing to keep

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a cow with high milk yield, good fertility, easy temperament, low feed requirement and high tropical disease resistance, in order of importance. The purchase price coefficient was negative, indicating that farmers prefer to pay less for improved dairy cows. The overall fit of the model was considered good, with a pseudo ρ^2 of 0.30. According to McFadden (1977), ρ^2 values ranging from 0.2 to 0.4 indicate good model fit.

Table 4.2 Estimates of overall dairy preference traits for smallholder dairy farmers in Tanzania.

	Coefficient \pm SE	p-value
Intercept	0.85 \pm 0.159	<0.0001
Milk yield	1.43 \pm 0.059	<0.0001
Fertility	0.85 \pm 0.050	<0.0001
Feed requirement	-0.56 \pm 0.092	<0.0001
Temperament	0.76 \pm 0.066	<0.0001
Disease resistance	0.48 \pm 0.048	<0.0001
Price	- 0.001 \pm 0.0003	0.0004
Rho-squared	0.30	
Number of observations	13,320	
LL of the model	-3,399.21	
LL of the model without predictors	-4,842.68	
<i>LL=Log Likelihood; SE= Standard error</i>		

The coefficients for the same traits chosen by farmers within different agro-ecological zones and dairy production systems are presented in Table 4.3. Coefficients for all traits were significant ($p<0.05$) for farmers in intensive production systems in both the Southern highland and Eastern coastal zones.

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Regarding extensive production system only the coefficient for disease resistance was significant in the Southern highland zone, whereas, all trait coefficients except for feed requirement were significant in the Eastern coastal zone. The price coefficient was only significant ($p < 0.05$) for the intensive dairy production system in the Eastern coastal zone. Moderate to high model fit values (0.33- 0.37) were observed except for the Southern highland extensive production system, which was characterised by the lowest amount of available data.

Table 4.3 Estimates of smallholder farmers' preference traits in two agro-ecological zones and production systems

	Southern highland zone				Eastern coastal zone			
	Intensive systems		Extensive system		Intensive systems		Extensive system	
	Coefficient \pm SE	p-value	Coefficient \pm SE	p-value	Coefficient \pm SE	p-value	Coefficient \pm SE	p-value
Intercept	0.04 \pm 0.247	0.85	1.74 \pm 0.718	0.016	2.88 \pm 0.343	<0.0001	0.03 \pm 0.345	0.92
Milk yield	2.16 \pm 0.088	<0.0001	0.12 \pm 0.295	0.691	0.78 \pm 0.126	<0.0001	1.14 \pm 0.128	<0.0001
Fertility	0.82 \pm 0.075	<0.0001	0.12 \pm 0.242	0.627	0.81 \pm 0.093	<0.0001	0.98 \pm 0.129	<0.0001
Feed requirement	-0.59 \pm 0.138	<0.0001	-0.04 \pm 0.424	0.925	-0.59 \pm 0.199	0.0028	-0.09 \pm 0.205	0.65
Temperament	0.70 \pm 0.095	<0.0001	0.12 \pm 0.305	0.700	0.36 \pm 0.12	0.0046	1.66 \pm 0.178	<0.0001
Disease resistance	0.52 \pm 0.077	<0.0001	0.52 \pm 0.235	0.026	0.36 \pm 0.092	<0.0001	0.72 \pm 0.111	<0.0001
Price	-0.001 \pm 0.0005	0.088	-0.002 \pm 0.0016	0.270	-0.002 \pm 0.0006	0.036	-0.001 \pm 0.0008	0.18
Rho-squared	0.37		0.18		0.33		0.33	
Number of observations	6,432		432		3,744		2,712	
LL of the model	-2,326.86		-129.74		-910.50		-666.53	
LL of the model without predictors	-1,465.04		-158.20		-1,364.48		-993.15	

LL=Log Likelihood SE= Standard error

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Table 4.4 presents the estimates of marginal willingness of the farmers to pay (MWTP) and the coefficients for their preferred traits in Southern highland and Eastern coast. Milk yield, fertility, temperament and disease resistance had positive MWTP, while feed requirement had negative MWTP values in both agro-ecological zones. The MWTP estimates shows the amount of money farmers are willing to pay for dairy cattle possessing traits of their interest on top or less to what they normally pay. In both agro-ecological zones, farmers were willing to invest for cows with high milk production, good fertility, easy temperament and high disease resistance. Conversely, farmers were willing to pay less for cows with high feed requirements. The confidence intervals for these values were high, demonstrating the magnitude of farmer variability in willingness to pay for cows with desired characteristics.

Table 4.4 Farmer marginal willingness to pay and preferences for each trait by agro-ecological zone

	Southern highland zone				Eastern coastal zone			
	1MWTP (£)	MWTP (£) 95% CI	Coefficient ± SE	p-value	MWTP (£)	MWTP (£) 95% CI	Coefficient ± SE	p-value
Intercept			1.17±0.712	0.100			2.73±0.677	<0.0001
Milk yield	404.42	172.05 - 2358.33	2.01±0.083	<0.0001	47.33	85.26 - 465.20	0.89±0.087	<0.0001
Fertility	156.02	57.99 - 944.66	0.77±0.071	<0.0001	147.34	76.93 - 517.02	0.89±0.074	<0.0001
Feed requirement	115.08	(- 581.18) – (- 42.07)	-0.57±0.130	<0.0001	-71.43	(-187.59) - (-31.48)	-0.43±0.138	0.0018
Temperament	134.93	44.94 - 826.51	0.67±0.090	<0.0001	138.70	64.82 - 520.97	0.83±0.100	<0.0001
Disease resistance	102.60	38.18 - 573.79	0.51±0.072	<0.0001	74.64	40.63 - 226.90	0.45±0.068	<0.0001
Price			-0.005±0.0025	0.005			-0.006±0.0023	0.0094
Rho-squared			0.34				0.31	
Number of observations			6,864				6,456	
LL of the model			-2,485.06				-2,357.62	
LL of the model without predictors			-1,629.07				-1,638.42	

LL=Log Likelihood; SE= Standard error; CI=Confidence interval; 1MWTP = marginal willingness to pay; £ = British pound sterling. Currency exchange rate: 1 British Pound = 2,956.04 Tanzanian shillings (31st July 2017 <https://www.xe.com>).

Discussion

Farmers' preferences and trade-offs of dairy cattle traits across agro-ecological zones and production systems

Results from the analyses across zones and production systems revealed the highest preferences for improved animal production (milk yield, fertility), welfare (good temperament) and adaptability (low feed requirement and tropical disease resistance) traits. Farmers were sensitive to high costs and suggested they would like to acquire improved dairy cattle at an affordable price.

Milk production had the highest positive significant coefficient, indicating that, above all, farmers would like cows with high genetic potential for increased milk yield. More emphasis on production traits compared to other traits indicates the priority of continued milk production for household income, as reported in previous studies (Swai and Karimuribo 2011; Gillah et al. 2014). The farmers' preference towards high milk production could be associated with an increase in per capita income and favourable policies towards increased milk production capacity and dairy product safety standards (URT 2013). A similar higher preference for cows with high milk production was previously reported in smallholder dairy farmers in Ethiopia (Duguma and Janssens 2016) and Kenya (Kariuki et al. 2017). Additionally, the preference for high yielding cows could be partly influenced by the existing multiple milk marketing channels. Previous reports showed that 70% of the milk produced in Tanzania reaches the consumer via informal milk marketing channels, also known as "milk hawkers". The remaining 30% of the milk produced reaches consumers through conventional marketing channels via milk collection centres linked to dairy processors (URT 2016).

Fertility had a positive significant coefficient, indicating that farmers preferred productive animals to ensure continued supply of milk. A profitable dairy enterprise depends on lifetime milk production and thus regular calvings.

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Fertility is broadly affected by the interaction of genetic and non-genetic factors (De Kruif 1978). Previous studies in Tanzania showed that both unreliable natural mating practices and poor artificial insemination services have led to long intervals between calving, long day open periods and a high number of services per conception (Msangi et al. 2005; Kivaria et al. 2006). Additionally, fertility might be affected by factors such as seasonal feed availability, climatic conditions, disease incidence and management practices (Mwatawala et al. 2002).

Our results showed that smallholder farmers preferred keeping cows with an easy temperament, as the third most important criterion after increased milk yield and fertility. Temperament was defined as the level of cow aggressiveness during handling or milking. Previous studies involving smallholder dairy farmers in Tanzania, Kenya, Uganda and Ethiopia have reported an easy temperament as an important trait when selecting dairy cattle (DGEA 2015). Preference for an easy temperament is associated with the use of family labour in feeding, milking, health management and breeding of dairy cattle. During the focused group discussion, farmers commented on active participation of women and children in feeding cows as the main reason for disliking cows with aggressive behaviour. Thus, to ensure continued interest in dairy production and possible adoption of new improved breeds, traits such as docility need to be considered in breeding scheme designs for smallholder dairy farmers.

Importantly, our results showed that most farmers preferred cows with low feed requirements for growth and milk production. Farmers were not willing to acquire cows that required high feed input to produce milk. Negative preference towards cows with a high feed demand and uptake can be related to the cut-and-carry feeding system, which is labour intensive. Preference for breeds with lower feed requirements could be associated with seasonal feed availability. Land shortage for pasture establishment and poor quantity and quality of forages during the dry season have been perceived as major constraints to the dairying activities in Tanzania (Kavana et al. 2005).

Another important trait used for selecting cows was resistance to tropical diseases such as East Coast Fever, Anaplasmosis, Babesiosis and Cowdriosis and trypanosomosis (Swai et al. 2010; Karimuribo et al. 2006). The coefficient for disease resistance was positive and highly significant, indicating that farmers' preferred cows that can withstand tropical disease challenges. Animal diseases are among the factors reported to affect the smallholder dairy sector in Tanzania. Common diseases which affect dairy cattle reported in previous studies include tick borne diseases, mastitis, contagious bovine pleuro-pneumonia, Foot and Mouth disease, trypanosomosis, helminthiasis and zoonotic diseases such as brucellosis and bovine tuberculosis (Swai et al. 2010; Karimuribo et al. 2006; MALF 2016). Poor utilisation of extension services, high cost of drugs, low adoption of vaccination programmes and poor disease reporting systems are among the factors contributing to high incidence of diseases (MALF 2016).

Cow purchase price was considered as one of the most important factors when selecting the preferred cow. The price coefficient was negative and highly significant, indicating that farmers preferred dairy cattle purchased at a low price. High prices and lack of market information of improved heifers have been reported as a major constraint in acquiring improved dairy cattle. The purchase price tends to be affected by breed type and production environment (DGEA 2015). Our results suggest that smallholder dairy farmers would benefit from a government policy ensuring an affordable price for improved animals. Therefore, the present study highlights the need for enhancing government policies, technologies and innovations to produce affordable improved dairy cattle for smallholder dairy farmers in Eastern Africa.

Farmers' preferences and trade-offs of dairy cattle traits in different agro-ecological zones and production systems

Despite being ranked relatively low in overall preference, disease resistance was the only animal trait viewed as significantly important amongst farmers in both agro-ecological zones and production systems. Otherwise,

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there were variations in the patterns described above. Thus, dairy farmers in intensive production systems in both agro-ecological zones indicated a high preference for cows with low feed requirements, which was not the case among their counterparts in extensive production systems. Furthermore, preferences for milk yield, fertility and temperament traits were specific to different agro-ecological zones and production systems. The variation of farmer preference traits across agro-ecological zones and production systems could be associated with environmental factors (availability of feed, disease prevalence) as well as infrastructure (e.g. milk marketing strategies, reliability of breeding services).

Animal production, welfare and adaptability traits were considered of the greatest importance for Southern highland intensive production systems. The highland regions are cooler and therefore have a more suitable climate for crossbred and purebred dairy cattle. Generally, dairy farm intensification occurs more rapidly in the highland zones due to small farm sizes for forage establishment (Swai & Karimuribo 2011). In addition, urban and peri-urban dairy farming by-laws advocate intensive feeding systems and a limited number of cattle per household. It could therefore be argued that favourable climatic conditions, production systems and local government by-laws have an impact on farmer preference traits.

The difference in farmer trait preference was evident between intensive and extensive systems for farmers in the Eastern coastal zone. In intensive husbandry systems, milk yield, fertility and low feed requirement were the top three most important traits preferred by smallholder dairy farmers. Preference for high production and adaptability traits in these areas is thought to be influenced by the Tanga Dairy Cooperative Union and Tanga Fresh Factory which is the main milk buyer. The Dairy Cooperative Union and milk processing factory provides inputs, milk collection facilities and a reliable market for the produced milk.

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In conclusion, from a farmer's viewpoint, the most important dairy traits included high milk yield, good fertility, easy temperament, low feed requirements and disease resistance. Farmers' trait preferences differed between agro-ecological zones and production systems due to variation of climatic conditions, feed resources and local infrastructure. Thus, adaptability to the local environment was considered as a fundamental trait for selecting dairy cattle. Farmers were willing to invest in improved dairy cattle showing desired traits at an affordable price. Results from the present study provide evidence for designers of breeding programmes to take consideration of specific farmers' preferred traits. Selection indexes and breeding strategies need to be developed based on the identified farmer preferred traits in the specific agro-ecological zones and production systems. Global warming and climate change present a serious threat to agriculture and food security and are a growing international concern. It has been well established that greenhouse gases (GHG) is a major contributing factor to global warming. However, traits related to GHG were not included in the choice experiment because they were not mentioned by farmers as priority traits during the focused group discussion. This study suggests that selection for reducing greenhouse gases should be considered in designing future breeding programmes.

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Compliance with ethical standards

Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional

and /or national research committee and with the 1964 Helsinki declaration and its later amendments or complete ethical standards.

Conflict of Interest Declaration

The authors of this paper declare that there is no conflict of interest.

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4.3 Chapter conclusion

This chapter has identified and documented, for the first time, a broad consensus of breeding goal traits in smallholder dairy production systems using a farmer-participatory approach. The study showed that a bottom up approach (farmer-led) breeding schemes design is feasible with farmers preferred traits being included in a breeding programme. From a farmer's viewpoint, the most important dairy traits included high milk yield, good fertility, easy temperament, low feed requirement and disease resistance. A smallholder farmer index comprising all these traits can be also developed, based on the relative emphasis placed by the farmers on each trait. The next chapter explores possible selection decisions and breeding strategies on the identified farmer preferred traits in different agro-ecological zones and production systems. The predicted rate of genetic gain of breeding goal traits from the different breeding schemes is also described in the next chapter.

**Chapter 5 Breeding strategies for improving
smallholder dairy cattle productivity
in Sub-Saharan Africa. A case study
of dairy farmers in Tanzania**

5.1 Introduction

The previous chapter (Chapter 4) identified farmer preferred traits in smallholder dairy systems. The study described farmer's trait preferences in different agro-ecological zones and production systems in Tanzania. This chapter examines the impact of genetic selection practices on addressing farmer-led breeding goals in smallholder dairy farming systems in Sub-Saharan Africa (SSA) using Tanzania as a case study. The chapter examines breeding strategies that are likely to be adopted by smallholder dairy farmers in order to improve the farmer- preferred traits of Chapter 4.

Earlier research undertaken in SSA has confirmed that the rate of genetic improvement for milk yield from indigenous breeds is low, ranging from 0 to 0.15% per year (Galukande et al. 1962; Mahadevan et al. 1962, Marshall et al. 2019). The indigenous and exotic dairy breeds have been often crossed in unsystematic ways to produce a mixture of breeds of varying genetic composition (Mujibi et al. 2019). Because of lack of clear crossbreeding and selection strategies, the resulting performance of the crossbreds has been unpredictable (Cunningham and Syrstad 1987). The F1 crosses have been considered to be superior compared to local breeds. However, upgrading to high grade exotics has resulted in a lack of animal adaptability and was often less economical than either generating F1 or improving indigenous ecotypes (Singh 2015).

Routine genetic evaluations and selection of the best animals according to the breeding goal is not a common practice for most countries in SSA (Opoola et al. 2019). Non-systematic crossbreeding of indigenous breeds to exotics from temperate countries, poor infrastructure and shortage of technical personnel are among of the limiting factors for genetic improvement of dairy cattle in SSA (Opoola et al. 2019, Galukunde et al. 2013). Breed preference has been often used as guide for choice of the best dairy animals instead of individual animal selection based on a well-defined breeding goal with relevant animal traits. Performance of F1 crosses reportedly depends on type of exotic

breed used and quality of breeding bulls selected within a breed (Vaccaro, Pérez, and Vaccaro 1999). For example, studies in the tropics have shown that Holstein-Friesian crosses offer the highest advantage for production traits while Jersey crosses have better fertility compared to the former (Singh 2015).

Systematic crossbreeding programmes involving temperate and tropical breeds have demonstrated a considerable benefit when they are well planned (McDowell 1985). Although crossbreeding has been adopted in SSA for more than one century, the smallholder dairy sector, which comprises the majority of dairy farmers, has not been able to achieve the desired gains. The major limitation includes lack of clear breeding strategies, mismatch of genotypes and environment and lack of farmer participation in designing the breeding programmes (Galukande et al. 2013). However, crossing of exotic milk breeds and indigenous breeds has been widely accepted as the fastest means of increasing dairy productivity.

Serious efforts to improve the dairy industry in Tanzania are currently underway (Michael et al. 2018; United Republic of Tanzania (URT) 2019). However, the success of genetic improvement programmes will need a structured breeding programme based on animal traits identified by farmers in Chapter 4. A selection index constructed from overall farmers' trait preference would be suitable for the majority of farmers across agro-ecological zones and production systems. In Chapter 4, we found that farmers' trait preferences differed across agro-ecological zones and production systems. Therefore, selection indexes combining trait and relative weights according to agro-ecological zone and production systems would be appropriate for sustainable cattle genetic improvement in smallholder dairy farming in Tanzania and potentially other parts of SSA.

The present chapter explores alternative breeding strategies to improve the biological efficiency of cattle for dairy production through selection. The chapter considers both improvement of indigenous cattle and crossbreeding. There has been extensive importation of exotic dairy cattle sires from different

countries of origin to SSA for crossbreeding with local ecotypes. Yet, there is insufficient evidence to recommend a specific breeding strategy based on the aspirations of farmers in different zones and production systems. Institutional policies that support the use exotic dairy breeds, and lack of organisation and management of breeding programmes have led to indiscriminate genetic blending and erosion of the genetic diversity in indigenous cattle (Nyamushamba et al. 2017). This is in contrast with developed countries where different indexes for a wider range of traits are used for selection of the best animals (Interbull, 2019).

A number of breeding strategies need to be tested to identify the ideal combination of exotics and indigenous cattle for different environment and production systems. While, farmers are often obliged to use any exotic bull available for crossbreeding, a clear breeding strategy must be developed to determine the most suitable exotic bulls for different agro-ecological zones. Systematic genetic selection and improvement of exotic breeds developed the in country of origin of exotic sires would warrant an increase in productivity. Alternative breeding strategies may include backcrossing the F1 with exotic sires or *inter se* mating to develop new synthetic breeds. The latter may be well suited to the local production environment as demonstrated by the Australian milking zebu (Donegan and Roberts 1984; Hayman 1974) and Jamaican Hope (Wellington et al. 1970). These are some examples of successful attempts to develop of productive and resilient breeds for tropical environments. Efforts to improve the dairy industry in SSA in general and Tanzania in particular are currently based on use of imported exotic bulls for crossbreeding and the creation of synthetic breeds such as Mwapwa cattle, which was examined in Chapter 3 of this thesis. The breeding programmes involves crossing indigenous breeds to exotic dairy cattle - mainly Friesian, Ayrshire and Jersey. However, despite the many years of importation of exotic breeds and continuous breeding and selection of improved dairy cattle, milk production in the country and region has remained low compared to developed countries (Chawala et al. 2017).

For a long time, the Tanzanian government, through the Ministries responsible for livestock development, has been responsible for providing all the necessary investment in dairy improvement programmes. However, Chawala et al. (2017; Chapter 3) reported low genetic progress for production and reproduction traits in centrally based dairy cattle breeding programme. Centrally breeding programmes in SSA have not been practically adopted by smallholder dairy farmers. Such examples include the Kilifi Plantation rotation programme in Kenya and Mwapwa cattle breeding programmes in Tanzania. Despite reported success on-station, these programmes have shown little impact as source improved genetics to smallholder dairy farmers in their respective agro-ecological zones (Chawala et al. 2017; Galukunde et al. 2013).

Chawala et al. (2019) documented the appropriate breeding objectives and selection criteria for the smallholder dairy farmers in Tanzania. However, the genetic selection strategy that will make a major contribution to the performance improvement of dairy cattle in Tanzania for the identified animal traits is still unclear. Therefore, there is a need to identify suitable breeding strategies for smallholder dairy farmers in Tanzania.

The aims of this Chapter were to develop dairy cattle genetic improvement strategies and determine genetic progress for the priority traits identified by farmers in smallholder dairy production systems. Three breeding strategies were evaluated; i) genetic improvement based on continuous importation of exotic bulls from temperate countries to Africa, ii) genetic improvement based on the development of a new synthetic breed with crossbreeding, iii) genetic improvement of indigenous populations based on domestic selection of indigenous bulls.

5.2 Materials and Methods

5.2.1 Breeding goal traits and selection indices

Breeding goals for smallholder dairy farmers were first established based on the five animal traits identified in Chapter 4. The emphasis coefficient (β -coefficients) of animal traits identified by farmers as a priority traits presented in Chapter 4 (Table 4.2) were used to quantify the amount of emphasis on each individual traits placed in selection indices for smallholder dairy farmers. Additional selection indices of exotic bulls in country of origin of exotic sires were considered based on the United Kingdom (UK) selection index (Agriculture and Horticulture Development Board (AHDB) 2018; Interbull 2019). Table 5.1 summarises these traits. Multi-trait selection indexes considering different trait combinations and differing amount emphasis for smallholder breeding goals traits were created, as shown in Table 5.1. According to Table 5.1, three selection indexes were developed:

- a) **Overall Farmer index:** this selection index comprised all five farmer preferred traits from Chapter 4.
- b) **Reduced Farmer index:** this selection index included the two most important and probably easiest to record farmer-preferred traits.
- c) **Exotic index:** this selection index combined all traits that are included in the UK selection index (AHDB 2018; Interbull 2019).

Table 5.1 Breeding goal traits and selection indexes with relative trait emphasis

Farmer preferences (Chapter 4)	Breeding goal traits (abbreviation)	Index for selection and weights on traits			Trait description and desired direction of change
		OFI (β)	RFI (β)	EI (£)	
High milk yield	Lactation milk yield (LMY)	1.43	1.43	-0.02	Kilograms of milk yield in a 305–day lactation; high milk yield is desirable.
Good fertility	Calving interval (CI)	-0.85	-0.85	-0.35	Number of days between two consecutive calvings; low numbers are desirable
Easy temperament	Temperament (TEMP)	0.76		0	Temperament score measured on a 1 to 9 scale; higher scores are desirable.
Feed utilisation efficiency	Mature live-weight (BWT)	-0.56		0	Average mature live weight (kg); aim is to avoid increasing.
Disease resistance	Lifespan (LF)	0.48		25.4	Lifespan score reflecting the number of lactations completed; higher values are desirable.
	Fat yield (Fat)			0.08	Kilograms of milk fat yield in a 305–day lactation; high fat yield is desirable.
	Protein yield (Protein)			1.71	Kilograms of milk protein yield in a 305–day lactation; high protein yield is desirable.
	Somatic cell count (SCC)			-0.19	Log-transformed milk somatic cell count as an indicator of mastitis; low values are desirable.
	Feet and legs (Feet)			1.13	Composite of linear type traits related to legs and feet measured on a scale of 50 to 90; high values are desirable.
	Mammary systems (Udder)			1.88	Composite of linear type traits related to udder measured on a scale of 50 to 90; high values are desirable.
	Non-return at 56 days (NR56)			2.16	Non-return to service after 56 days: 1= return to service; 2=no return to service (i.e. presumed to have conceived; high values are desirable.

OFI = Relative weights for an Overall Farmer Index (β from Chapter 4); RFI= Relative weights for a Reduced Farmer Index (β from Chapter 4); EI = Economic weights for an Exotic Index reflecting the UK selection index and including additional traits (AHDB, 2018; Interbull, 2019; Pritchard et al. 2013, Wall et al. 2005a).

5.2.2 Breeding strategies

Three basic breeding strategies were investigated (Table 5.2). The first breeding strategy constituted a continuous upgrading of the indigenous cattle by repeated crossing with selected exotic bulls from temperate countries of origin of exotic sires. This strategy reflected a systematic version of the prevailing approach in smallholder dairy farming systems, which mostly involves utilisation of imported exotic bulls from temperate countries. Within the first strategy, four separate breeding scenarios were investigated: i) selection of exotic bulls semen based on the Overall Farmer Index (Table 5.1) of the five farmer-preferred traits (Chapter 4), ii) selection of exotic bulls semen based on a Reduced Farmer Index (Table 5.1) comprising the two most important and easiest to record traits (milk yield and calving interval), iii) selection of exotic bulls semen based on an Exotic index (Table 5.1) from the country of origin of exotic sires and iv) random selection of exotic bulls. The exotic population was improved separately using the exotic index.

The second breeding strategy led to the development of a new synthetic breed. Exotic bulls were first selected based on the Overall Farmer Index (Table 5.1) and crossed with indigenous to produce F1. Thereafter, elite crossbred bulls were selected within the new population, with each generation based on the same index.

The third breeding strategy was set up to improve the indigenous population by selecting the best indigenous bulls based on the Overall Farmer Index (Table 5.1).

In all breeding strategies, the selected bulls were available for artificially inseminate 30%, 50% and 100% of the female population. Where this proportion was less than 100%, the remaining population was assumed to mate randomly with locally unselected bulls.

Table 5.2 Breeding strategies and selection scenarios of dairy cattle in smallholder dairy farms

Breeding strategy	Scenario
Strategy A: Genetic improvement through continuous importation of selected exotic sires leading to a gradual upgrade of the indigenous population	Scenario 1: Selection of exotic sires based on Overall Farmer Index (Table 5.1)
	Scenario 2: Selection of exotic sires based Reduced Farmer Index (Table 5.1)
	Scenario 3: Selection of exotic sires based on Exotic Index (Table 5.1)
	Scenario 4: Random Selection of exotic sires
Strategy B: Creation of new synthetic breed through importation of selected exotic sires in first generation and subsequent selection of crossbred sires	Scenario 5: Selection of sires based on Overall Farmer Index (Table 5.1)
Strategy C: Genetic improvement of indigenous population through genetic selection of local sires	Scenario 6: Selection of indigenous sires based on Overall Farmer Index (Table 5.1)

5.2.3 Simulation study for the evaluation of breeding strategies

A simulation study was designed and conducted to determine the effectiveness of each breeding strategy based on predicted genetic selection response over 15 generations. The simulation study is described next.

5.2.3.1 Population description

a) Size, exotic and indigenous populations

The size of both exotic and African indigenous populations in each generation was 1,000 males and 1,000 females (50% males, 50% females). The breeding population was distributed in 20 villages each with a herd size of 100 animals. The average herd size in smallholder in SSA is 1 to 5 animals per farm. The simulation assumed a herd size of 100 breeding cows in the village would constitute a herd. Each breeding scenario was simulated for 15 generations of 10 replicates each. Results pertained to the average of the 10 replicates. Cows were kept within the herd and no

replacement of heifers were considered. A sire selection intensity of 10% was assumed for improvement of the exotic population in strategy A and the improvement of the indigenous population in strategy C.

b) Simulation input parameters

i) *Phenotypic means for breeding goal traits*

Phenotypic means of all farmer preferred traits for exotic and indigenous cattle were obtained from the literature. Improved zebu (Sahiwal and Boran) cattle breeds were used as local / indigenous breeds for Tanzania. Phenotypic averages for breeding goal traits in temperate and African production environment are shown in Table 5.3.

Table 5.3 Phenotypic average describing performance of exotic and indigenous cattle for farmer preferred traits.

Trait	Exotic breed performance in country of origin of exotic sires	Exotic breed performance in Africa	Indigenous breed performance in Africa
LMY (kg)	8,065 [‡]	4,050 [¥]	1,363 [#]
CI (days)	402 [‡]	462 [¥]	450 [†]
TEMP (1-9 scale)	5.5 [‡]	4.7 [*]	4.7 [*]
BWT (kg)	648 ^π	557 [*]	337 [§]
LF (number of lactations)	4.7 [‡]	2.68 ^ψ	2.7 ^π

Source: [‡] Pritchard et al. 2013, [‡] Interbull 2019, ^π Pérez-Cabal and Alenda 2003, [¥] (Ayalew et al. 2015; Ojango and Pollott 2001; Opoola 2018), ^{*} Parameter scaled to African environment, ^ψ Kern et al. 2014, [#] Ilatsia et al. 2007, [†] (Haile-Mariam and Kassa-Mersha 1994; Ilatsia et al. 2007; Wasike et al. 2009), [§] (Ilatsia et al. 2011), ^π (Musingi et al. 2018). LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations).

ii) Genetic correlations among traits

Genetic correlations among traits were assumed to be the same in all populations and environments. For exotic sires, genetic correlations for the same traits expressed in their country of origin and in Africa were obtained from Interbull 2019. Table 5.4 shows the genetic correlations among traits (off-diagonal) and the genetic correlations for the same traits in exotic bulls expressed in their country of origin and in Africa (diagonal).

Table 5.4 Genetic correlations among all simulated traits (above the diagonal) and between the country of origin of exotic sires and Africa for the same trait (along the diagonal).

Traits	LMY ‡	Fat †	Protein †	LF ‡	SCC †	Feet †	Udder †	NR56 †	CI ‡	BWT ‡	TEMP ‡
LMY	0.81	0.61	0.85	0.00	0.18	-0.07	0.00	-0.42	0.47	0.23	0.44
Fat		0.81	0.69	-0.13	0.19	-0.04	0.00	-0.30	0.46	0.26	0.24
Protein			0.81	-0.14	0.22	-0.07	0.00	-0.43	0.45	0.25	0.25
LF				0.9	-0.07	0.64	0.26	0.08	-0.50	-0.10	0.18
SCC					0.92	0.04	-0.21	-0.12	0.13	0.23	-0.41
Feet						0.93	0.21	-0.16	-0.01	0.03	0.21
Udder							0.98	-0.10	0.14	-0.24	0.20
NR56								0.8	-0.35	-0.19	0.11
CI									0.87	0.01	0.05
BWT										0.94	-0.02
TEMP											0.85

LMY= milk yield (kg) in a 305 day lactation; Fat = Fat yield (kg) in a 305 day lactation, Protein = Protein yield (kg) in a 305 day lactation, LF = longevity (number of lactations), CI = calving interval (days), BWT = mature live body weight (kg), SCS = Log-transformed somatic cell count score, Feet= Composite of linear type traits related to legs and feet (50-90 scale), Udder = Composite of linear type traits related to udder (50-90 scale), NR56 = Non-return to service (1=returned to service, 2=Conceived and did not return to service), TEMP = temperament score (1-9 scale).

‡ Chawala et al. 2019, † PLI traits (Interbull 2019), # Genetic correlations of the same trait between country of origin of exotic sires and Africa

iii) Variances and covariances for breeding goal traits

Genetic variances of all farmer preferred traits for exotic animals in both their country of origin and in Africa and for indigenous cattle in Africa were obtained from the literature (Table 5.5). Genetic covariances among different traits within and between the different countries were calculated from the correlations expressed in Table 5.4 (off-diagonal) and the variances from Table 5.5. Genetic covariances for the same traits expressed in the country of origin of exotic sires and in Africa by the imported exotic bulls were obtained from the correlations expressed in Table 5.4 (diagonal) and the variances from Table 5.5. Covariance between the two traits was derived as follows.

$$cov_{gxy} = r_{gxy} * \sqrt{\delta_{gx}^2 + \delta_{gy}^2}$$

Where, cov_{gxy} is the genetic covariance between trait x and y; r_{gxy} is the genetic correlation coefficient between trait x and y, δ_{gx}^2 and δ_{gy}^2 are genetic variances for trait x and y.

Environmental variances were only considered in Africa, either for imported exotic animals or indigenous animals. Environmental variances were calculated from the correspondent genetic variances (Table 5.5) and heritabilities (Table 5.5). Environmental covariances among traits were assumed to be 0.

Table 5.5 Genetic variance and heritabilities (in parenthesis) describing performance of exotic and indigenous cattle for farmer preferred traits

Trait	Exotic breed performance in country of origin of exotic sires	Exotic breed performance in Africa	Indigenous breed performance in Africa
LMY (kg)	557,440.00 (0.55) [‡]	360,274.00 (0.29) [¥]	353,422.44 (0.21) [#]
CI (days)	137.72 (0.02) [‡]	272.00 (0.05) [¥]	246.28 (0.03) [†]
TEMP (1-9 scale)	0.10 (0.10) [‡]	0.10 (0.10) [*]	0.10 (0.10) [*]
BWT (kg)	501.00 (0.32) ^π	442.68 (0.32) [*]	211.00 (0.20) [§]
LF (number of lactations)	0.43 (0.06) [‡]	0.15 (0.09) ^ψ	0.06 (0.04) ^τ

Source: [‡] Pritchard et al. 2013, [‡] Interbull 2019, ^π Pérez-Cabal and Alenda 2003, [¥] (Ayalew et al. 2015; Ojango and Pollott 2001; Opoola 2018), ^{*} Parameter scaled to African environment, ^ψ Kern et al. 2014, [#] Ilatsia et al. 2007, [†] (Haile-Mariam and Kassa-Mersha 1994; Ilatsia et al. 2007; Wasike et al. 2009), [§] (Ilatsia et al. 2011), ^τ (Musingi et al. 2018). LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations).

Considering the differences in climatic conditions between the SSA and temperate countries, the genetic value of imported animals is expected to differ when performing in SSA. Exotics are expected to perform better in the country of origin of exotic sires than in an African environment. This would reflect on the genetic correlations between temperate exporting regions and Africa; for the purposes of the present study, these were obtained from the Interbull (https://interbull.org/ib/maceev_archive) website using UK as proxy for country of origin of exotic sires and South Africa estimates as a proxy for SSA. Table 5.6 shows the genetic variance (along the diagonal) and covariance (above the diagonal) of farmer-preferred traits for exotics in the country of origin of exotic sires, exotics in Africa and indigenous African populations.

Table 5. 6 Genetic variance (along the diagonal) and covariance (above the diagonal) of farmer preferred traits for exotics in the country of origin of exotic sires, exotics in Africa and indigenous African populations

Traits	LMY	CI	BWT	LF	TEMP
Exotics in the country of origin					
LMY	557,440.00	4,118.09	3,843.67	0.00	112.61
CI		137.72	2.63	-3.56	0.20
BWT			501.00	-1.33	-0.15
LF				0.43	0.08
TEMP					0.10
Exotics in Africa					
LMY	360,274.00	4,652.63	2,904.63	0.00	76.95
CI		272.00	3.47	-2.86	0.24
BWT			442.68	-0.72	-0.12
LF				0.15	0.04
TEMP					0.10
Indigenous in Africa					
LMY	353,422.44	4,384.85	1,986.17	0.00	76.21
CI		246.28	2.28	-1.93	0.23
BWT			211.00	-0.35	-0.09
LF				0.06	0.01
TEMP					0.10

LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations).

c) Breeding values, phenotypic values and heterosis

i) Breeding values

A semi-stochastic simulation was designed to simulate a base population of exotics and indigenous, true breeding values (TBVs) and environmental values (ENVs) of animal traits. The TBVs and ENVs of traits were simulated from a multivariate normal (MVN) distributions $MVN(0, \mathbf{G})$ and $MVN(0, \mathbf{E})$, where \mathbf{G} and \mathbf{E} are the corresponding genetic and environmental variance-covariance matrices.

The importation or selection of parents to breed the next generation was based on the estimated breeding values (EBVs). EBVs were generated for each trait as a correlated distribution with the TBVs, assuming an accuracy

equal to r and a distribution $N(0, r^2 \sigma_a^2)$, where σ_a^2 was the variance of the corresponding trait. EBVs estimations were assumed to be performed through univariate analyses (Raphaka et al. 2018; Sanchez-Molano et al. 2014). The accuracy of selection was assumed to be different between exotics in their country of origin and indigenous in Africa. (The accuracy of selection reflects the accuracy of sire genetic evaluation and was calculated using the formula by Oldenbroek and Waaij, 2015. It was assumed that, sires were selected based on the performance of their daughters. The number of daughters per progeny tested bull was assumed to be 100 in the country of origin of exotic sires and 25 for indigenous in Africa.

Animal's individual EBVs were combined in the corresponding selection index (Table 5.1). Animals were ranked based on their index and selected to become sires of the next generation either by importing (importation scenarios) or by selection (new synthetic and indigenous improvement scenarios).

In subsequent generations, TBVs of the offspring of two animals were estimated from the average TBVs of the parents plus an individual Mendelian sampling (MS) term to account for random sampling of parental alleles. Thus, TBVs were calculated as follows:

$$TBV_{Offspring} = 0.5 * (TBV_{Sire} + TBV_{Dam}) + MS_{TBV}$$

The Mendelian sampling term for TBVs followed a distribution $MVN(0, 0.5(1 - \bar{F}) \mathbf{G}_0)$, where \bar{F} is the average inbreeding coefficient of the parents and \mathbf{G}_0 is the variance-covariance matrix of the base population. For crossbred animals, \mathbf{G}_0 was a combination of the genetic variance-covariance matrices weighted by the proportions of genes from the indigenous and exotic populations. In all generations after the base population, ENV was simulated from $MVN(0, \mathbf{E})$, with \mathbf{E} being a mixture of the environmental variance-covariance matrices weighted by the proportions of genes from the indigenous and exotic populations.

EBVs of the offspring were estimated at the time of selection and importation of exotic sire semen, following the method described before and assuming an accuracy r (accuracies were assumed to be constant across generations) and a distribution $N(0, r^2 \sigma_a^2)$, where σ_a^2 was the variance of the corresponding trait in the actual generation the animals pertained to (Raphaka et al. 2018; Sanchez-Molano et al. 2014).

ii) Phenotypic values

Finally, for each trait, the phenotype y of animal i was simulated by adding the phenotypic mean (μ) to the TBV and ENV of each animal. Thus the phenotypic value for each individual animal was computed as follows:

$$Y_i = \mu + TBV_i + ENV_i$$

The above formula was used to generate traits for exotic animals in Europe, exotic in Africa and indigenous or crossbred in Africa.

The simulation of base population was designed in three steps. Firstly, a base population of exotic dairy cattle in the country of origin of exotic sires was simulated. The exotic population was selected and improved based on EBV generated using the Exotic Index (5.1). Secondly, in order to account for the lower performance of imported exotic animals in SSA, the African performances of the exotics were simulated following the variance covariance matrix previously described in Table 5.6. Thirdly, a base population of indigenous cattle was also simulated based on phenotypic and genetic parameters for African cattle (Tables 5.3, 5.4, 5.5 and 5.6). The initial indigenous population was used as base for upgrading and establishment of a new synthetic breed, according to breeding strategies A and B (Table 5.2).

iii) Heterosis

In order to assess the phenotypic progress to the breeding strategies, heterosis and recombination loss were calculated for each offspring based on proportion of exotic genes for sire and dam. Estimate for the coefficients of

heterosis (β_h) and recombination loss (β_r) for the crossbreds were calculated as follows (Dickerson 1973; Wall et al. 2005b).

$$\beta_h = P_S(1 - P_D) + P_D(1 - P_S)$$

$$\beta_r = P_D(1 - P_D) + P_S(1 - P_S)$$

Where P_S and P_D are the proportion of exotic genes for the sire and dam, respectively. Afterwards, trait phenotype was calculated as follows:

$$Phenotype = TBV + \beta_h * Max.H + \beta_r * Max.R$$

Where, $Max.H$ = Maximum value for heterosis and $Max.R$ = Maximum value for recombination loss.

The maximum values of heterosis ($Max.H$) and recombination loss ($Max.R$) for the breeding goal traits are presented in Appendix I, Table 1.

5.2.3.2 Selection

For breeding strategy A, EBVs for each trait were estimated and combined based on corresponding selection indices as described in Table 5.2. Thus, the imported exotic sires were used to upgrade the indigenous cattle population. New exotic sires were selected in every generation.

For the synthetic breed (strategy B), EBVs for each trait were estimated and combined based on the Overall Farmer Index. Exotic bulls from the base generation were selected and crossed with indigenous cattle to create generation F1. Sires were then selected within F1 based on the Overall Farmer Index to produce F2, then similarly selected within F2 to produce F3 and the mating process was repeated in subsequent generations. New crossbred sires were selected in every generation.

For the indigenous cattle selection strategy, indigenous sires were selected based on the Overall Farmer Index as parents of the next generation. New indigenous bulls were selected in every generation.

The effect of increasing the percentage of cows bred to selected sires was investigated considering 30%, 50% and 100% of cows bred with Artificial Insemination (AI). These percentages were chosen based on the current AI utilization (30%; Mwanga et al. 2019), an expected increase to 50% in the near future (African Dairy Genetic Gains (ADGG), 2017) and a longer term plan for 100% implementation of AI in Tanzania (Michael et al. 2018; United Republic of Tanzania (URT) 2019).

5.2.3.3 Evaluation of breeding strategies

Results from each breeding strategy and scenario were averaged across 10 replicates. For each trait, the mean and variance of TBV and average proportion of exotic genes were calculated per generation. The effectiveness of each breeding strategy was assessed based on genetic and phenotypic progress per individual trait. Comparison indices were built based either on TBVs (genetic) and phenotypes (phenotypic) in order to compare all traits simultaneously.

5.2.4 Sensitivity analyses

A sensitivity analysis was carried out to assess the impact of changing genetic and phenotypic parameters on genetic and phenotypic progress. Three sensitivity analyses were carried out as follows:

5.2.4.1 Sensitivity analysis I: Impact of different indices in agro-ecological zones

Chapter 4 results indicated that farmer's trait preferences were mainly influenced by agro-ecological conditions and production systems. Overall farmer indices were calculated by agro-ecological zone based on β – coefficients for breeding goal traits for Overall Farmer Index – highland (semi-temperate) and Overall Farmer Index – coast (tropics). Comparisons were performed based on the predicted genetic progress of indices and individual breeding goal traits in the southern highlands and coastal agro-ecological zones. The three breeding strategies were evaluated based on genetic Overall Farmer Index.

5.2.4.2 Sensitivity analysis II: Impact of reduced performance of exotics in Africa with regards to farmer preferred traits

The performance of exotics in Africa was reduced by 25% compared to values in Table 5.3. Thus, the phenotypic mean for LMY was reduced from 4,050 to 3,038 kg, CI increased from 462 to 578 days, TEMP reduced from 4.7 to 3.5 score, BWT increased from 557 to 648 kg and LF decreased from 2.68 to 2.0 lactations. Comparisons were performed based on the predicted genetic progress of indices and individual breeding goal traits. The three breeding strategies were evaluated based on genetic Overall Farmer Index, Overall Farmer Index –Highland and Overall Farmer Index – Coast.

5.2.4.3 Sensitivity analysis III: Consequences of decreasing longevity of exotics in Africa and introducing an antagonistic genetic correction between LMY and LF

Adaptability of dairy cattle tend to differ according to the environment. Furthermore, the genetic correlation between production and survival or fitness traits is often antagonistic. Therefore, expected longevity of exotic cattle in Africa was reduced by 25% and the genetic correlation between LMY and LF changed from 0 to -0.34 according to Pritchard et al (2013). Comparisons were performed based on the predicted genetic progresses of indices and individual breeding goal traits between base simulation and this sensitivity analysis. The three breeding strategies were evaluated based on genetic Overall Farmer Index of this sensitivity analysis and the base simulation.

5.3 Results

5.3.1 Population structure in different breeding strategies

Figure 5.1 shows the levels of exotic genes in the population across generations in the six breeding scenarios outlined above. Results pertain to 100%, 50% and 30% Artificial Insemination (AI) mating schemes. In the strategies of importation (upgrading) and synthetic breed formation, the rate of replacement of the indigenous population increased depending on proportion

of AI penetration. For example, the levels of exotic genes in upgrading scenarios (1, 2, 3 and 4; strategy A) at generation five were 96.9%, 76.4% and 55.5% for 100%, 50% and 30% AI schemes, respectively. When developing a new synthetic breed, the percentage of exotic genes varied depending on proportion of indigenous population involved in formation of the foundation stock. The maximum percentage of exotic genes in the newly created synthetic breed was 50%, 31.1% and 18.5% for 100%, 50% and 30% AI mating schemes, respectively.

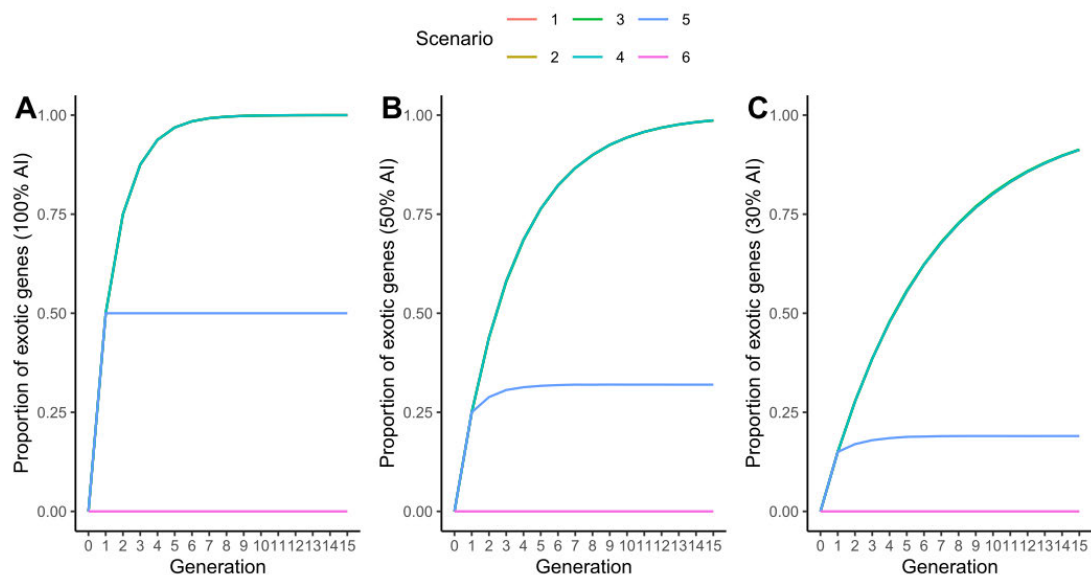


Figure 5.1 Proportion of exotic genes in six breeding scenarios at 100%AI (A), 50%AI (B) and 30%AI (C) mating schemes.

Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

5.3.2 Predicted genetic progress in individual breeding goal traits

The simulation assumed that selection of exotic sires was performed in every generation in a pure-breeding programme in the country of origin of exotic sires based on the Exotic Index (Table 5.1). Figure 1 in Appendix II

illustrates the predicted genetic progress (TBV trends) of animal traits included in the breeding goal in the country of origin of exotic sires. When importing sires to SSA, importation was based on any of the first four breeding scenarios in strategy A described in Table 5.2. Genetic trends of the farmer preferred traits (Chapter 4) for all six breeding scenarios are presented in Figure 5.2. Results in Figure 5.2 pertain to the 100% AI mating scheme. Results for all AI mating schemes considered in the present study are presented in Figure 2 in Appendix II.

Figure 5.2 demonstrates a clear difference in genetic trends of traits between the importation/upgrade strategy (scenarios 1, 2, 3, and 4), the new synthetic breed strategy (scenario 5) and improvement of the indigenous population strategy (scenario 6). Genetic trends in scenarios 1, 2, 3 were very similar. The genetic trend for scenario 4 lagged slightly compared to the other three scenarios under the importation/upgrade strategy.

Genetic progress for LMY, the most important trait according to farmer preferences (Chapter 4), was highest for the importation/upgrading strategy (scenarios 1, 2, 3, 4) compared to new synthetic breed strategy (scenario 5) and the improvement of indigenous population strategy (scenario 6). There are substantial differences in performance of the three strategies regarding LMY. The genetic trends of LMY for scenarios 1, 2 and 3 (all within the importation strategy) were very similar. However, scenario 4 (random importation of exotics) showed relatively lower genetic progress for LMY compared to scenarios 1, 2 and 3. At generation 15, the genetic progress for LMY in scenarios 1, 2, 3, 4 and 5 was 1.68, 1.70, 1.72, 1.59 and 1.32 times greater compared to scenario 6. Across 15 generations, the average TBV for LMY in scenarios 1, 2, 3, 4, 5 and 6 increased by 5.97, 6.05, 6.10, 5.63, 4.75 and 3.55 fold, respectively, compared to the base population LMY of 1,363 kg.

Calving interval (CI), the second most important trait according to farmer preferences (Chapter 4), was predicted to increase slightly in all the six scenarios despite having a negative relative weight in all selection indexes. CI

has strong and unfavourable genetic correlations with production traits (0.45 to 0.47). Importation scenarios produced animals with increased CI. Increase for CI reflects increased emphasis on LMY in the selection indexes. Notably, the genetic trends for CI shows that there was a small gap among the breeding strategies. Genetic trends of CI for scenarios 1, 2, 3 and 4 were relatively similar. At generation 15, the genetic progress for CI in scenarios 1, 2, 3, 4 and 5 was 1.04, 1.05, 1.05, 1.05 and 1.04 times greater compared to scenario 6. Across 15 generations, the TBV for CI in scenarios 1, 2, 3, 4, 5 and 6 had a 1.06, 1.07, 1.07, 1.06, 1.04 and 1.02 fold increase, respectively, compared to the base population CI of 405 days.

Genetic trend for TEMP increased in the preferred direction in all breeding scenarios. The increase in TEMP was dictated by a favourable genetic correlation with LMY (0.44), protein (0.25), fat (0.24) and LF (0.18). The genetic progress for TEMP after 15 generations of selection in breeding scenarios 1, 2, 3, 4 and 5 was 0.95, 0.92, 0.90, 0.90 and 1.04 times greater compared to scenario 6. After 15 generations, the TBV for TEMP in scenarios 1, 2, 3, 4, 5 and 6 increased by 1.28, 1.24, 1.20, 1.20, 1.40 and 1.34 folds, respectively, compared to the base population TEMP score of 4.7.

The genetic trends for BWT increased initially for breeding scenarios 1, 2, 3 and 4 because of a moderate positive genetic correlation with production traits (0.23-0.26) in the Exotic Index. There was no difference in genetic trends of BWT among scenarios 1, 2 and 3 but there was a considerable lag between them with scenario 4 (random selection in importation). At generation 15, the genetic progress for BWT in scenarios 1, 2, 3, 4 and 5 was 1.83, 1.87, 1.88, 1.85 and 1.34 times greater compared to scenario 6. After 15 generations of selection, the TBV for BWT in scenarios 1, 2, 3, 4, 5 and 6 increased by 1.74, 1.78, 1.79, 1.76, 1.28 and 0.95 fold, respectively, compared to the base population BWT of 337 kg.

Predicted genetic progress for LF was in the intended direction in all breeding scenarios. Greater genetic progress for LF was seen in the

importation strategy (scenarios 1, 2, 3 and 4) compared to the new synthetic breed (scenario 5) and indigenous improvement (scenario 6) strategies. This was due to the positive weight on LF in both the Exotic and the African Overall Farmer Index. At generation 15, the genetic progress for LF in scenarios 1, 2, 3, 4 and 5 was 1.22, 1.16, 1.18, 1.14 and 1.11 times greater compared to scenario 6. After 15 generations of selection, the TBV for LF in scenarios 1, 2, 3, 4, 5 and 6 improved by 1.54, 1.47, 1.49, 1.43, 1.40 and 1.26 folds, respectively, compared to the base population LF of 2.7 lactations.

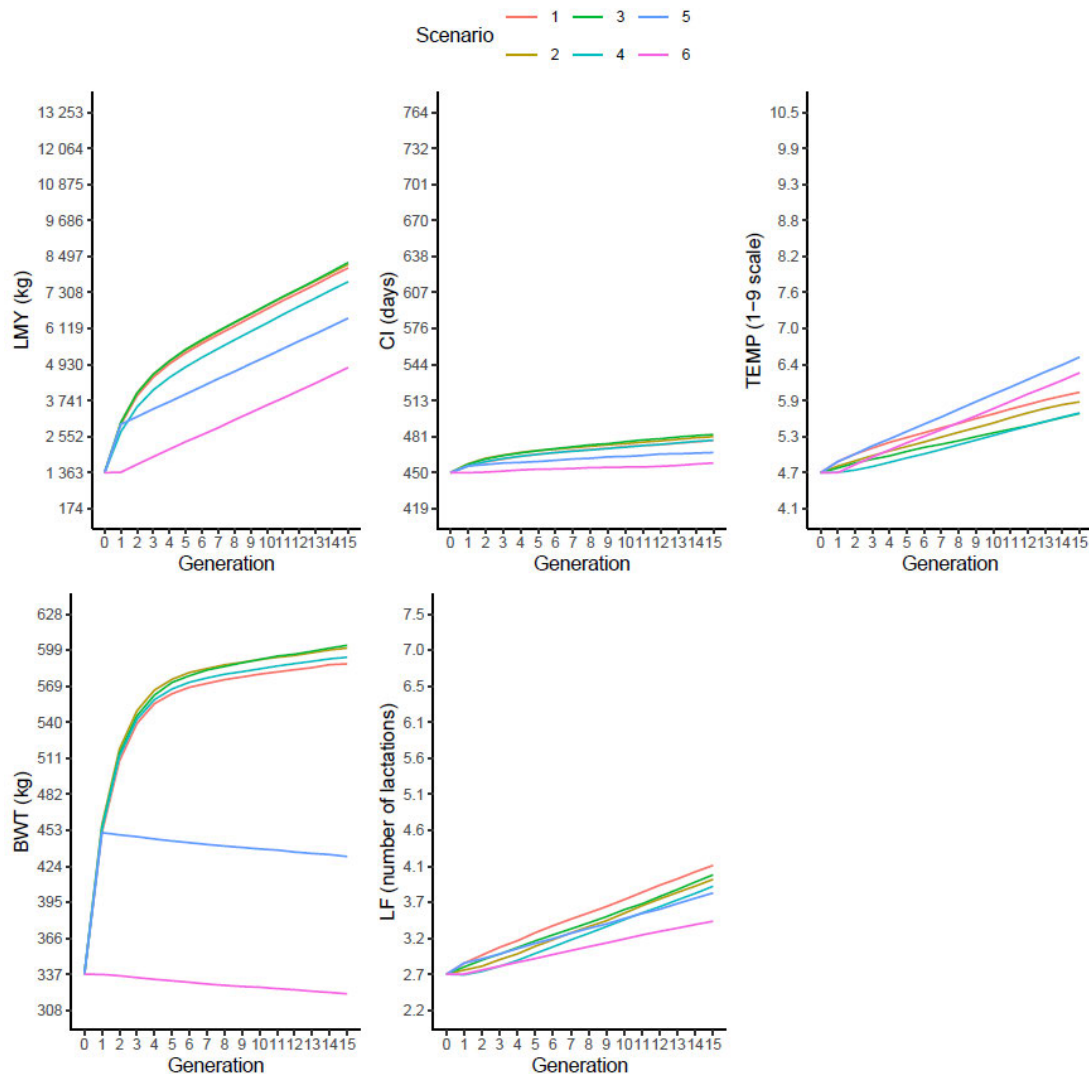


Figure 5.2 Predicted genetic progress per generation for six breeding scenarios for 305 day milk yield (LMY), calving interval (CI), temperament (TEMP), mature live weight (BWT) and longevity (LF) assuming 100% AI mating scheme.

Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

Table 5.7 summarises the genetic gain per generation for each trait under the different breeding scenarios and AI schemes. Overall, increase in proportions of AI penetration was favourable for LMY, LF and TEMP while

lower AI uptake was advantageous for BWT and CI. Table 1 and Table 2 in Appendix III present the rate of genetic gain separately for generations 1 to 5 and generations 6 to 15. Overall, the rate of genetic progress was higher in generations 1 to 5 (early selection) compared to generations 6 to 15.

Table 5.7 Average predicted genetic gain of breeding goal traits per generation, breeding scenario and Artificial Insemination (AI) scheme

AI Scheme	Breeding Scenario	LMY (kg)	CI (days)	BWT (kg)	LF (No. lactations)	TEMP (1-9 scale)
100%	1	375.4	1.62	10.33	0.09	0.08
	2	380.2	1.72	10.78	0.09	0.08
	3	383.3	1.91	11.12	0.09	0.06
	4	359.7	1.62	10.55	0.08	0.07
	5	279.2	0.97	1.12	0.07	0.12
	6	239.7	0.52	-1.09	0.05	0.11
50%	1	389.2	1.68	13.77	0.08	0.08
	2	395.4	1.85	14.41	0.08	0.07
	3	397.3	1.93	14.57	0.08	0.06
	4	364.6	1.66	13.99	0.07	0.06
	5	158.9	0.38	1.61	0.04	0.07
	6	135.3	0.27	-0.62	0.03	0.06
30%	1	352.0	1.48	14.02	0.07	0.06
	2	357.9	1.64	14.69	0.06	0.06
	3	361.3	1.78	14.76	0.06	0.05
	4	326.2	1.47	14.25	0.05	0.04
	5	97.1	0.17	0.98	0.02	0.04
	6	83.2	0.13	-0.42	0.02	0.04

LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

5.3.3 Predicted genetic progress in the Overall Farmer Index

The genetic progress achieved in the six breeding scenarios with regards to the genetic Overall Farmer Index are shown in Figure 5.3. Importation strategy (scenario 1, 2, 3 and 4) ranked higher compared to the synthetic breed strategy (scenario 5) and indigenous breed improvement (scenario 6) strategy. Genetic progress from the selection index for importation scenarios 1, 2 and 3 were better than scenario 4. At generation 15 in the 100% AI scheme, the genetic progress in scenario 1 was 1.25 and 1.76 times greater compared to scenario 5 and scenario 6, respectively. Genetic progress was affected by type of AI schemes; expectedly, genetic progress increased with increasing percentage of AI. The latter also narrowed the gap between the importation strategy on the one hand and synthetic breed and indigenous improvement strategies on the other.

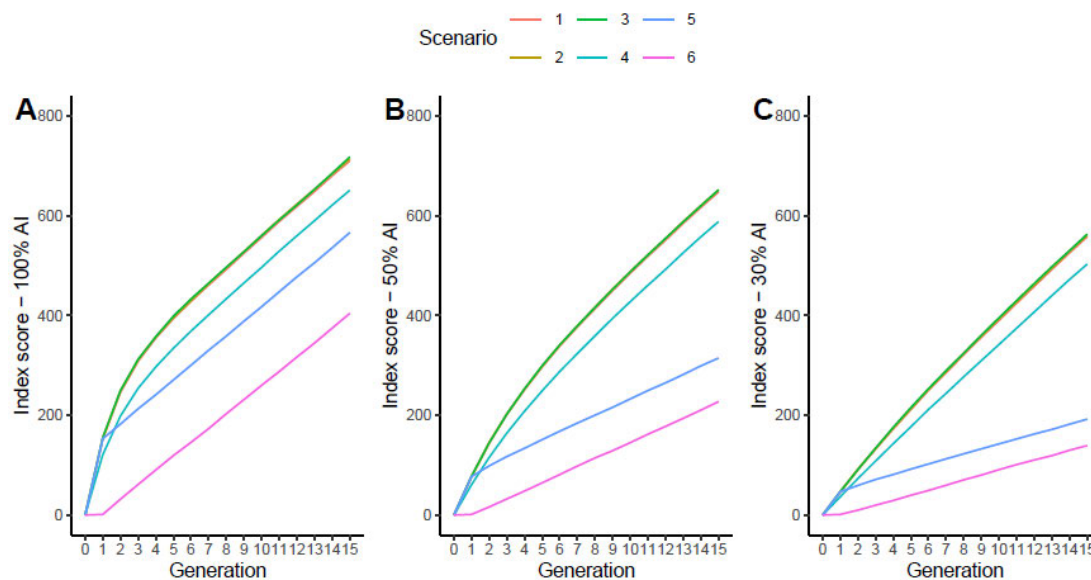


Figure 5.3 Predicted genetic progress per generation for six breeding scenarios for the Overall Farmer Index assuming 100% (A), 50% (B) and 30% (C) AI schemes. Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

5.3.4 Predicted phenotypic progress in individual breeding goal traits

Predicted phenotypic progress (trends) for individual breeding goals traits assuming 100% AI scheme are shown in Figure 5.4. In general, the slopes of phenotypic trends from generation 0 to 1 for LMY, CI, BWT and LF were steeper than for genetic trends (Figure 5.2). The phenotypic performance of F1 was higher than the additive genetic merit due to maximum heterosis in the crossbred offspring. Phenotypic values of traits decreased in first backcross and in F2 due to recombination loss (unfavourable effect). A desired direction of the phenotypic trends was observed in subsequent generations in response to selection. LMY and LF increased while CI was reduced. The relatively flat trend of BWT from generation six and above reflects a stable mature live weight due negative emphasis of BWT in the Overall Farmer Index. Figure 1 in Appendix IV illustrates predicted phenotypic progress of animal traits at all AI schemes.

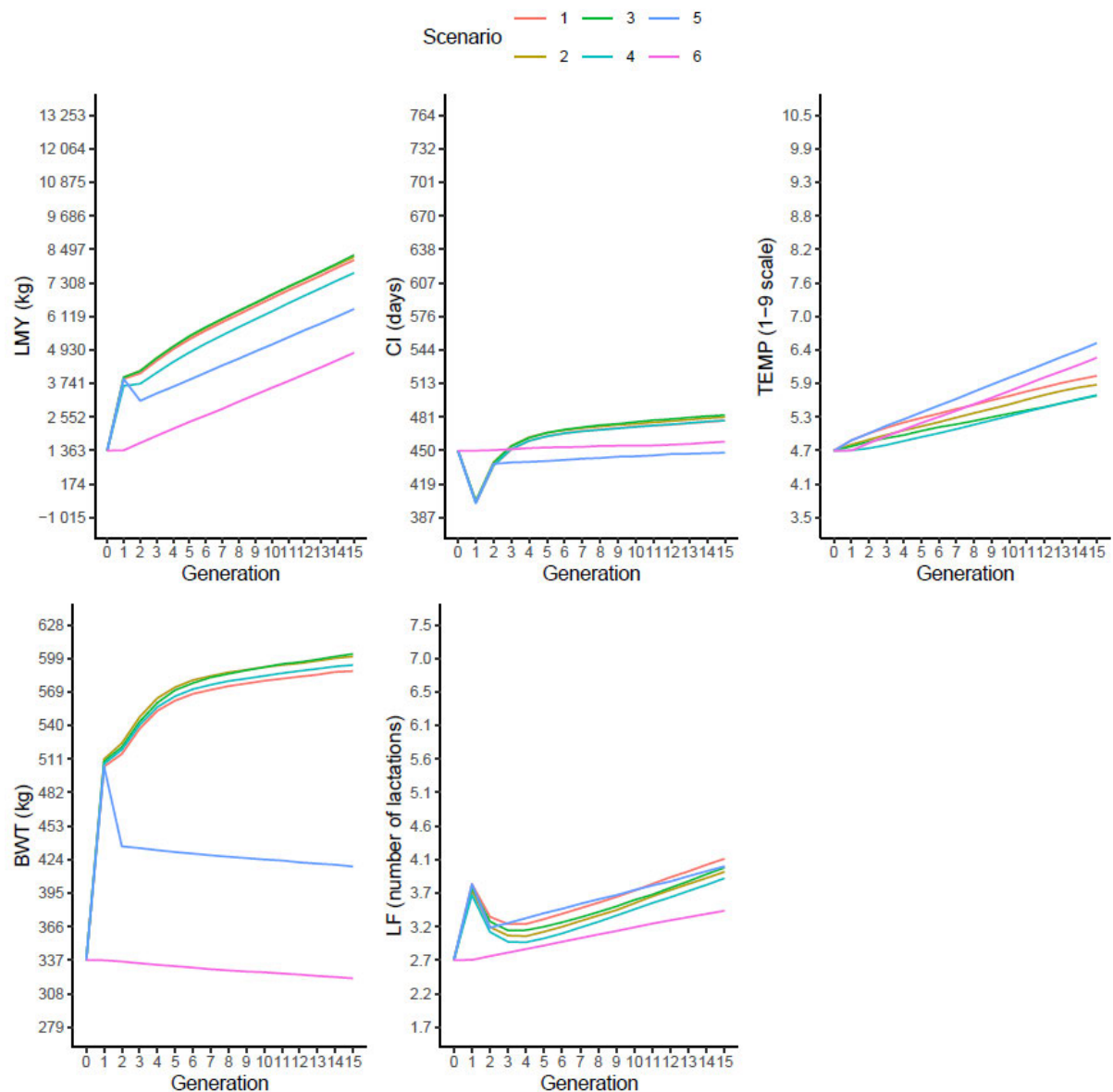


Figure 5.4 Predicted phenotypic progress per generation for six breeding scenarios for 305 day milk yield (LMY), calving interval (CI), temperament (TEMP), mature live weight (BWT) and longevity (LF) assuming 100% AI mating scheme.

Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

5.3.5 Predicted phenotypic progress in the Overall Farmer Index

Figure 5.5 shows the predicted phenotypic progress for the phenotypic Overall Farmer Index under the six breeding scenarios. With 100% AI scheme, the phenotypic progress for scenario 1 at generation 15 was 1.15 and 1.60 times better compared to scenarios 5 and 6, respectively. Higher predicted phenotypic progress was associated with higher percentage of AI. As with genetic trends, differences in phenotypic performance between the importation strategy and the new synthetic breed and indigenous improvement strategies increased with decreased AI uptake.

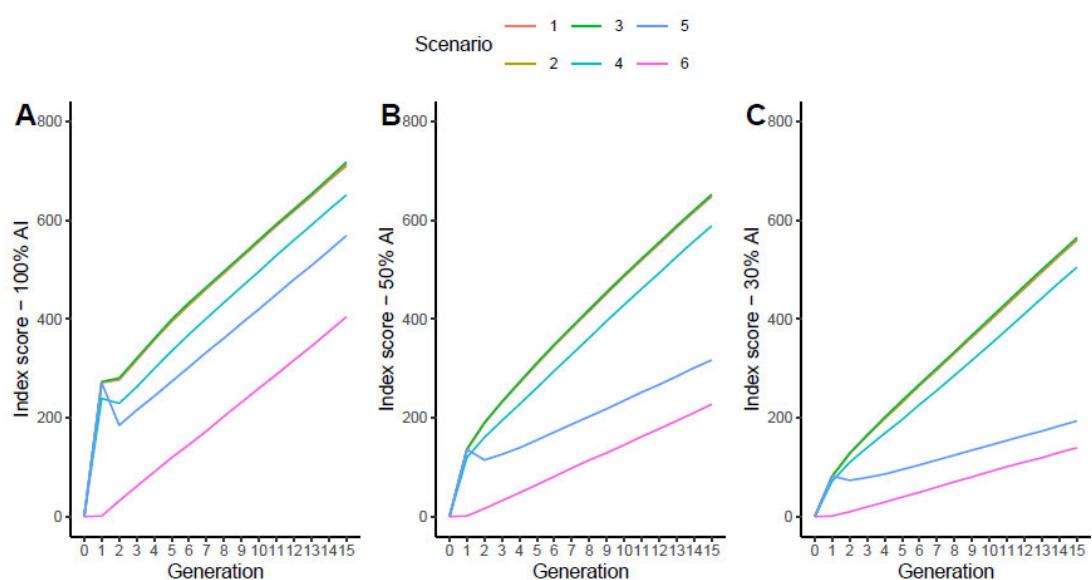


Figure 5.5 Predicted phenotypic progress per generation for six breeding scenarios.

Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

5.3.6 Inbreeding coefficients

The average inbreeding coefficient per generation for the six breeding scenarios are shown in Figure 5.6. The respective slopes at 100% AI was 0.15% for scenarios 1, 2, 3, 5 and 6, and 0.14% for scenario 4. The corresponding slopes at 50% AI for scenarios 1, 2, 3, 4, 5 and 6 were 0.14%, 0.13%, 0.14%, 0.12%, 0.08% and 0.08%, respectively. Similar slopes were observed for the 30% AI scheme. No significant differences in rate of inbreeding per generation between the six breeding scenarios at 100% AI was evident. However, there was a considerable difference at 50% and 30% AI schemes, where the rate of inbreeding was higher under the importation strategy compared to the other two.

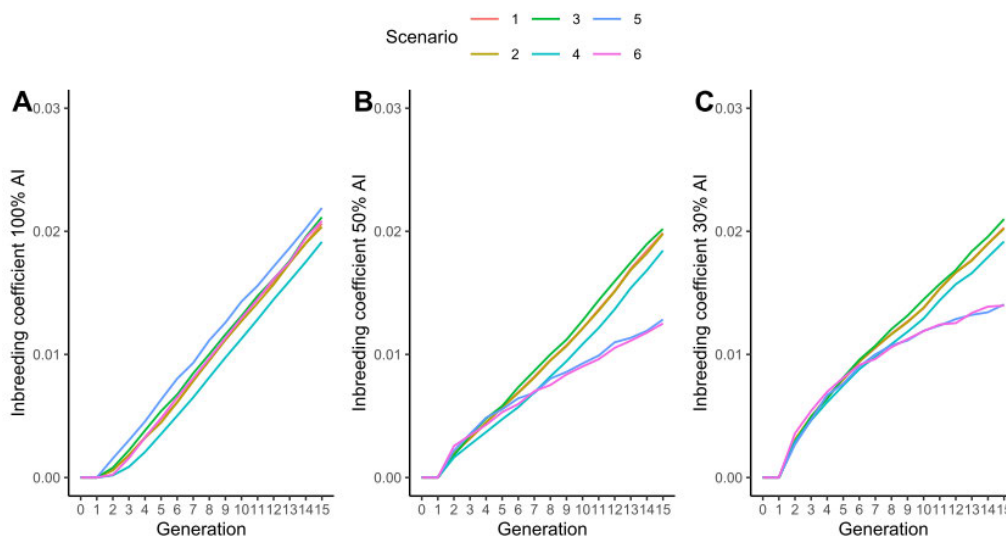


Figure 5.6 Average inbreeding coefficient per generation, breeding scenario and percentage AI scheme.

Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

5.3.7 Sensitivity analyses

The results of sensitivity analysis are presented in scenarios where major difference have been found. Scenario 1 (importation strategy), scenario 5 (synthetic breed strategy) and scenario 6 (indigenous cattle improvement strategy) were chosen to show the impact on genetic progress for animal traits and selection indexes. Scenario 1 was picked as reference scenario for comparison with scenario 5 and 6. The differences in genetic progress between scenarios were expressed as relative percentage differences or percentage change.

5.3.7.1 Sensitivity analysis I: Impact of different indices in agro-ecological zones

The predicted genetic progress of selection indexes (Appendix V: Figure 1 and 2) and individual breeding goal traits (Appendix V: Figure 3 and 4) were calculated using different farmers' preference weight of traits in the southern highlands and coastal agro-ecological zones. In both zones, genetic progress for importation scenarios exceeded that of synthetic breeds and indigenous improvement strategies. The differences in genetic progress for traits and selection indexes between scenarios 1, 5 and 6 are shown in Table 5.8. Sensitivity analysis showed that goal traits and selection indexes were sensitive to changes in preference weight based on agro-ecological zones. Overall the differences in genetic selection response between scenarios were smaller in highlands compared to coastal areas. For example, the difference in selection index response between scenario 1 and 5 in the coastal zone at 100% AI (28.72%) was twice that in the highland zone (14.66%). Differences between scenarios became smaller with increased proportion of AI uptake. The differences for the individual animal traits between highlands and coastal zones are presented in Table 1 of Appendix V.

Table 5.8 Relative differences (%) in predicted genetic gain after 15 generations of selection based on the Farmer Index in the highland and coastal zones between Scenarios 1 (Importation strategy), 5 (Synthetic breed strategy) and 6 (Indigenous breed improvement strategy).

				Difference (%) of selection indexes between scenarios	
				Scenario 1vs 5*	Scenario 1 vs 6*
Type of index	AI Scheme				
Overall Farmer Index –					
Highlands	100%			14.66%	37.07%
	50%			47.02%	61.74%
	30%			61.99%	72.47%
Overall Farmer Index – Coast	100%			28.72%	39.78%
	50%			57.11%	69.47%
	30%			63.86%	73.27%

*Scenario 1 vs. 5 = Relative difference (%) in selection response for scenario 5 in comparison to scenario 1; 1 vs. 6 = Relative difference (%) in selection response for scenario 6 in comparison to scenario 1.

5.3.7.2 Sensitivity analysis II: Impact of reduced performance of the exotics in Africa

Reducing the performance of exotic breeds in Africa by 25% scenario affected predicted genetic progresses for individual animal traits and the Overall Farmer Index. Table 5.9 shows the differences of predicted genetic progress for breeding scenarios 1, 5 and 6 across and within agro-ecological zones. In general, even in this worst-case scenario, importation based on the Overall Farmer Index scenario performed better compared to the new synthetic breed and indigenous cattle improvement strategies. Results for all traits and indexes are summarised in Appendix VI (Table1 and Figure 1, 2, 3, 4, 5 and 6).

Table 5.9 Relative differences (%) in predicted genetic gain after 15 generations of selection based on the Overall Farmer Index across and within agro-ecological zone between Scenarios 1 (Importation strategy), 5 (Synthetic breed strategy) and 6 (Indigenous breed improvement strategy); performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design.

		Difference (%) of selection indexes between scenarios for 25% worst case scenario	
Type of index	AI-Scheme	Scenario 1 vs 5*	Scenario 1 vs 6*
Overall Farmer Index	100%	10.70%	24.74%
	50%	47.59%	52.35%
	30%	61.11%	65.18%
Overall Farmer Index – Highlands			
	100%	5.93%	19.86%
	50%	44.62%	50.97%
	30%	58.91%	64.35%
Overall Farmer Index – Coast			
	100%	19.75%	28.39%
	50%	52.09%	54.97%
	30%	63.51%	65.84%

*Scenario 1 vs. 5 = Relative difference (%) in selection response for scenario 5 in comparison to scenario 1; 1 vs. 6 = Relative difference (%) in selection response for scenario 6 in comparison to scenario 1.

5.3.7.3 Sensitivity analysis III: Impact of reduced adaptability for exotics in Africa and an antagonistic genetic correlation between production and adaptability traits

When the longevity of exotic dairy cattle was reduced from 2.68 to 2.0 lactations and the genetic correlation with milk changed from zero to -0.34 (antagonistic), the predicted genetic progress decreased for both the individual traits and the indexes. In addition, differences between breeding scenarios were smaller compared to the base simulation. Appendix VII (Table 1 and Figure 1 and 2) shows a comparison of the predicted genetic progresses of

selection indexes and individual breeding goal traits between base simulation and this sensitivity analysis. The differences in genetic progress for selection indexes between scenarios 1, 5 and 6 are shown in Table 5.10. Sensitivity analysis showed that selection indexes were sensitive to changes in genetic correlation between production and adaptability traits for the Overall Farmer Index. Overall the differences in genetic selection response between scenarios were smaller in sensitivity II compared to base simulation. For example, the difference in selection index response between scenario 1 and 5 in base simulation at 100% AI (20.26%) was higher compared to the sensitivity III (13.11%).

Table 5.10 Relative differences (%) in predicted genetic gain after 15 generations of selection based on the Overall Farmer Index between Scenarios 1 (Importation strategy), 5 (Synthetic breed strategy) and 6 (Indigenous breed improvement strategy); an antagonistic correlation between animal production and fitness (longevity) was assumed combined with reduced fitness of the exotic sires in Africa.

		Difference (%) of selection indexes between scenarios	
Type of index	AI-Scheme	Scenario 1 vs 5*	Scenario 1 vs 6*
Overall Farmer Index (Base simulation)	100%	20.26%	43.06%
	50%	51.41%	64.89%
	30%	65.55%	75.02%
Overall Farmer Index (Sensitivity III)	100%	13.11%	37.57%
	50%	48.24%	62.16%
	30%	63.60%	72.89%

*Scenario 1 vs. 5 = Relative difference (%) in selection response for scenario 5 in comparison to scenario 1; 1 vs. 6 = Relative difference (%) in selection response for scenario 6 in comparison to scenario 1.

5.4 Discussion

The overall aim of this chapter was to investigate alternative dairy cattle breeding strategies for smallholder dairy farmers and identify the most appropriate strategy, which could be used as a guide for future dairy cattle breeding programmes in Tanzania and SSA at large. Results demonstrated that different levels of progress in dairy productivity may be achieved through sire genetic evaluation and selection. The study quantified the relative merit of three distinct breeding strategies: (i) upgrade of the indigenous population through systematic importation of exotic sire semen and crossing, (ii) development of a new synthetic breed based on first generation crossing between indigenous and imported exotics and within generation selection thereafter, and (iii) genetic improvement of the indigenous population based on domestic selection. Selection criteria in different breeding scenarios included the Overall Farmer Index, a Reduced Farmer Index and an Exotic Index. All breeding strategies were assessed based on the genetic and phenotypic progress of the Overall Farmer Index and its constituent traits, as described in Chapter 4.

5.4.1 Genetic and phenotypic progress

The breeding strategy based on importation of exotic sire semen and crossing with cows locally was superior with regards to genetic and phenotypic progress of the Overall Farmer Index. Importation scenarios ranked higher compared to the synthetic breed and indigenous breeds' improvement strategies. As expected, selection on the Overall Farmer Index under the importation strategy was the best and random selection was the worst. After 15 generations of selection the genetic gains from continuous importation of animals based on Overall Farmer Index were 8.31% - 9.83% higher compared to randomly importing from the country of origin of exotic sires. Results from the three breeding strategies showed a positive genetic progress of all breeding goal traits over generations. Increasing the proportion of cows bred by improved sires through artificial insemination (AI) resulted in a greater

genetic progress for all selection scenarios. The superiority of the importation breeding strategy compared to synthetic breed and within indigenous breed breeding strategies may be attributed to the high relative emphasis on milk yield placed by the smallholder farmers. Additionally, the importation strategy benefited from parallel genetic selection in the country of origin of exotic sires (based on the Exotic Index);

Estimates of heterosis were in the desirable direction for all traits manifested by increased 305-day milk yield (LMY), shorter calving interval (CI), reduced mature live weight (BWT,) increased longevity (LF) and better temperament (TEMP) in the F1. Phenotypic performance declined in crossbreds in subsequent generations compared to the F1 due to recombination losses. Nevertheless, positive trends continued to be observed due to the impact of genetic selection. A detailed discussion of the genetic and phenotypic progress due to selection for individual breeding goal traits is provided below; traits are discussed in order of priority in the African Overall Farmer Index.

5.4.1.1 305 day milk yield

Milk has been previously considered as principal source of protein and income for smallholder dairy farmers in SSA (Salami et al. 2010; Somda et al. 2005). The results from the present study show a substantial increase in genetic progress for milk yield in all breeding strategies considered because LMY was the most emphasised trait in the Overall Farmer Index. Indeed, the relative weight of LMY in the index was twice compared to CI, TEMP and BWT, and three times compared to LF. Therefore, results demonstrate the potential of breeding for high milk yield in smallholder dairy production systems. The large difference in LMY assumed between the exotics and the indigenous cattle populations, with the exotic bulls being highly productive, was the main factor for the success of the importation strategy over the synthetic breed and indigenous improvement strategies. In addition, the heritability of LMY was greater compared to other traits in all production environments. The synthetic

breed strategy had lower LMY compared to importation but was still competitive due to the use of selected crossbred sires. Overall, the genetic trends for LMY in the different breeding strategies were positive indicating the impact of selection of best sires in every generation.

The phenotypic trend for milk showed again the superiority of F1 with respect to the indigenous base population in all crossbreeding strategies. A decline in performance observed after F1 was the result of breaking favourable ancestral gene combinations according to Mendel's law of independent assortment (Dickerson 1973; Rutledge 2001).

Large heterosis reported between *Bos taurus* and *Bos indicus* can also be explained by the large genetic divergence between the two populations (Lin et al. 2010; Loftus et al. 1994; Syrstad, 1985). Previous studies have concluded that the optimum proportion of milk production in tropics is achieved for crosses with about 50% exotic genes and the synthetic breed strategy led to this gene composition when 100% AI scheme was adopted (Cunningham and Syrstad 1987). This was based on the good performance of F1 followed by decrease in performance in high-grade animals. Galukande et al. 2013 reported the LMY for 50 to 75% *Bos taurus* crossbred dairy cattle in the tropics being 2.2-2.7 times higher than that of *Bos indicus*. However, increasing exotic genes resulted in lower milk yield compared to crossbreds with 50% *Bos taurus* genes. Rutledge (2001) highlighted that the decrease in performance in the F2 is a result of recombination loss and not because of poor breeding programme designs. Superiority of LMY in the subsequent generation observed in the present study was mainly due to the advantage from using selected sires from the previous generations.

5.4.1.2 Calving interval

Shorter CI (calving interval) is important for increased length of productive life, income, lifetime profit and overall genetic progress (Do et al. 2013). Longer calving intervals decrease a cow's lifetime productivity, cause shifts in calving patterns and increase the chances of animal culling (Olori et

al. 2002). The present study showed a small genetic progress in the undesired direction for CI. This was mainly due to the positive (unfavourable) genetic correlation between CI and LMY suggesting that selection emphasis on increased milk yield would result in longer calving intervals. The importation breeding scenarios led to longer CI due to higher milk production compared to the synthetic breed and indigenous improvement scenarios. In addition, CI has a relatively low heritability suggesting that the trait could be improved faster by changes in herd management practices.

The importance of heterosis for CI was more prominent in the synthetic breed strategy compared to importation. Mungube et al. (2019) reported an estimated loss of about US\$40 million due to long calving intervals of 450 to 500 days in Kenya's dairy industry. In the present study we would expect reduced profitability for the importation breeding strategy because of longer calving intervals. The economic losses due to longer CI could be minimised by building capacity for accurate heat detection, improved feeding and regular check-up for reproductive diseases.

Calving interval was chosen here as proxy trait for fertility, which was the second most important trait listed in the African Overall Farmer Index. Recording of calving interval requires minimal data i.e. two successive calving dates. However, one of the drawbacks of calving interval is that the relevant records become available in later stages of the cow's production cycle compared to other measure of fertility traits. However, this draw back can be overcome by the use of genomic breeding values. Future considerations of traits affecting fertility in early stages of life and production cycle such as age at first calving, non-return rate, number of services per conception and days open would be warranted but solid recording practices need to be in place in this regard.

5.4.1.3 Temperament

Results showed that selection for temperament (TEMP), the third most important trait in the Overall Farmer Index, was feasible for crossbred cattle in

Africa. Temperament was assumed to be the same in the base generation of selection in both the exotic and indigenous populations. Therefore, any difference in TEMP between breeding strategies was mainly due to the AI scheme adopted, relative weight in selection index, and genetic correlation with production, fitness, conformation and fertility traits. It was interesting to note that importation strategies had better temperament than synthetic and indigenous animals at the 50% and 30% AI schemes. These results support the idea that *Bos taurus* breeds have better TEMP than *Bos indicus* breeds (Piovezan, Cyrillo, and da Costa 2013). Our results showed that increase in AI uptake to 100% AI favoured increase in TEMP in the synthetic and indigenous breeds mainly due to the advantage of exotic genes in the population and high relative emphasis of TEMP in the Overall Farmer Index (0.83) compared to the Exotic Index (0).

The relationship between temperament and life-time production efficiency for dairy cattle has been previously investigated (Haskell et al. 2014; Neja et al. 2015). Neja et al. (2015) revealed a positive correlation between TEMP and LMY in Polish Holstein-Friesian. The reported difference was 621 kg of milk between calm cows and cows with normal temperament. This implies that calmer cows will increase farm productivity and profitability. Haskell et al. (2014) published a review paper in which they reported a favourable relationship between TEMP and productivity, health and fitness traits. TEMP is also important for human safety at milking and during handling. Chawala et al. (2019) associated preferences for docile cows in smallholder dairy farmers in Tanzania with the use of family labour in feeding, milking, health management and breeding of the animals.

5.4.1.4 Mature live weight

Mature live weight (BWT) was used here as a proxy to feed utilisation efficiency. Feed utilisation efficiency was the fourth priority animal trait in farmer preferences (Chapter 4). Upgrading the indigenous cattle with exotic sire importation and crossing resulted in cows with heaviest BWT. The large

difference in BWT between the exotics and the indigenous cattle populations, with the exotic bulls having bigger BWT than indigenous, was the main factor for the heavier cows in the importation strategy over the synthetic breed and indigenous improvement strategies. Despite a negative weight for BWT in the Overall Farmer Index, the increase in BWT in the importation strategy was influenced by moderate heritability (Ilatsia et al. 2011; Pérez-Cabal and Alenda 2003) and a positive genetic correlation with milk yield (LMY) (Pérez-Cabal and Alenda 2003). The overall genetic trends for LMY and BWT showed that selection for LMY would influence BWT. The importation breeding strategy resulted in most productive cows but with heavier mature live weight. Conversely, the genetic progress for BWT for the synthetic breed and indigenous improvement strategies decreased slightly with the increase in the generation number due to negative emphasis for BWT in the Overall Farmer Index. In the first generation, the indigenous population was mated only once with the exotic sires to generate F1. The F1 sires were selected using the Overall Farmer Index to mate with F1 females to produce F2 with the mating procedure repeated in the subsequent generations". Similarly, the indigenous population was selected using the Overall Farmer Index. In contrast, the importation strategies resulted in cows with heaviest BWT because of upgrading the indigenous breeds with exotics sires having bigger BWT.

Heterosis effects on BWT were greatest for the importation breeding strategy. In practice, high heterosis for BWT is undesirable because of the negative emphasis on feed utilisation efficiency. BWT in the synthetic breed was lower because of negative selection and high recombination loss in generations after the F1 due to *inter se* mating. This means that the importation strategy would produce cows with increased feed requirements, whereas the other strategies would result in lighter cows with low feed requirements.

When addressing the relationship of BWT with other traits, fertility of heifers is often related to mature live weight (Freetly et al. 2011). A delayed growth towards mature live weight means a prolonged age at first service of breeding heifers. Also calving problems are mainly associated with low live

body weight at mating. Studies have shown that increasing live body weight at calving was associated with increased milk production for the first lactating cows (Bazeley 2016; Moran 2012). On the other hand, heavier animals had higher maintenance requirements for growth and milk production (Moran 2012). Due to smaller land areas for growing fodder and long dry seasons, smallholder dairy farmers in Africa do not have enough feed resources to feed large heifers and cows. Therefore, this justifies breeding for smaller heifers in SSA. Exotic high-grade dairy cattle with higher BWT are expected to perform better in semi-temperate highland areas, where the climate is cooler. Chawala et al. (2020), highlighted the importance of growing improved pastures and promoting recycled food waste and by-products as a way of assuring feed availability all year round in smallholder dairy systems.

5.4.1.5 Longevity

Longevity (LF) was considered here as a proxy for disease resistance, which was the fifth priority trait established by smallholder farmers (Chapter 4). Disease is often the key reason for involuntary culling, leading to shortened productive life and, hence, reduced longevity. Longevity is currently being considered in breeding goals for dairy cattle worldwide (Interbull 2019). The heritability of the trait is often low (Kern et al. 2014; Musingi et al. 2018). In addition, there is an unfavourable genetic correlation between the longevity and production traits such as milk, fat and protein (Pritchard et al. 2013). In the present study we demonstrated that a combination of selection and crossbreeding may lead to higher genetic gains for longevity in African dairy cattle. The genetic progress for LF was higher for the importation breeding strategy. Crossbreeding followed by selection will increase the number of lactations completed (productive longevity). Selection for LF ensures an increase in overall production performance without compromising animals' fitness. Number of lactations completed was chosen here for consistency between the Overall Farmer and the Exotic indices. Also, this is an indicator of efficiency since an increase in number of lactations completed translates to increase in milk production. However, it should be noted that the phenotypic

difference for LF (productive longevity) between exotic and indigenous used in this study were minimal. It is expected that the difference in genetic progress for longevity between exotic and indigenous may be large if resistance to tropical diseases and parasites will be opted as an alternative definition for LF. Farmers Index was similar in scenarios 5 and 6 due to the smaller genetic difference of the base population of the two scenarios. Musingi et al. (2018) highlighted that an increase in proportion of animals with longer longevity would increase herd productivity due to reduced risk of culling. However, Pritchard et al. (2013) indicated that, although farmers would prefer highly productive cows, in the long-term they may experience shorter longevity due to diseases challenge, reduced fertility and high feed requirements.

The phenotypic progress in the present study showed that LF in the synthetic breed was comparatively similar to upgrading via importation. Overall, the phenotypic trend for longevity was positive indicating that all studied breeding strategies would improve longevity of dairy cattle in Africa.

5.4.1.6 Predicted genetic and phenotypic progress in the Overall Farmer Index

Higher proportion of AI uptake resulted in a greater genetic and phenotypic progress for all selection indexes. This was due to increase in proportion of indigenous cattle mated with selected sires contributing towards the improvement of the breeding goal. In general, increasing the proportion of AI in breeding population narrowed the differences in productivity across scenarios. Interestingly, adoption of 50% AI may result in a relatively high proportion of genetic gains achieved by 100% AI adoption, especially under the importation/upgrade strategy. As AI uptake increased, the genetic progress increased up to a point followed by a plateau. This explains the high genetic progress for LMY, CI and BWT at 50% AI (Table 5.7) due to admixture of population of animals with different levels of exotic genes. The impact of heterosis and recombination loss was larger for scenario 5 (Strategy B) and scenario 4 (Strategy A, random selection) compared to scenarios 1, 2 and 3 (Strategy A). Recombination loss in the ensuing generation resulted in a

decreasing trend in some scenarios when AI was 100%. After generation 3, the direction of the index was favourable due to selection. In general, increasing the proportion of cows that are bred with elite selected bulls contributed to high predicted genetic and phenotypic gains.

5.4.2 Implications of proportion of cows participating in a breeding programme and agro-ecological zone on genetic progress

AI services have been established as a way of harnessing the genetic potential of dairy sires from country of origin of exotic sires where progeny testing is usually implemented. However, the coverage of AI for most countries in SSA is low and variable. A recent survey study by Mwanga et al. (2019) reported AI utilisation in 13.46%, 31.46%, 50.35% and 56.50% of the dairy cattle in Uganda, Tanzania, Ethiopia and Kenya, respectively. In the present study, we demonstrated how predicted genetic gain may increase by increasing the proportion of cows that are bred with elite selected bulls. As expected, the success of the studied breeding strategies would depend on improved AI uptake in combination with a systematic breeding programme being in place.

The genetic progress for individual goal traits and selection indices varied depending on the agro-ecological zone cattle were raised in. The importation and synthetic breed strategies were favoured more in the highland zone compared to the coastal zone. Nevertheless, importation strategy was better than synthetic and indigenous strategies in both agro-ecological zones. This is due genetic advantage for LMY for importation strategy compared to other strategies. In base populations the LMY for exotics was 5.8 times high compared to indigenous breeds. These findings broadly support previous studies in this area linking high productivity of animals in highland zones with favourable semi-temperate climate compared to the predominantly tropical climate in lowland and coastal zones. Dairy cattle with an increasing proportion of exotic genes are generally considered less adapted to tropical conditions and, therefore, some level of management and environmental modification

need to be made to counter-balance this effect and increase productivity. For example, improved housing and feed availability would keep the high-grade exotic dairy cows reasonably healthy and productive. This, however, could be costly and perhaps unrealistic sometimes. Non-upgrading strategies (synthetic and indigenous improvement) may be promoted in the tropical coastal areas where the production environment is less favourable for the upgrades. The economic benefits of synthetic breed over upgrades and indigenous breed in smallholder systems has been reported in many regions of the tropics (Galukande et al. 2013). The new synthetic breed strategy could, for example, start by targeting the smallholder production systems in coastal zone where milk yield and fertility traits are equally important.

5.4.3 Inbreeding

The rate of inbreeding in all breeding scenarios studied was low, with an increase of 0.08-0.14% per generation. Trends in inbreeding reached a maximum of 2% per generation after 15 generations of selection. These findings are consistent with that of Chagunda et al. (2018) who reported an average inbreeding of 0.8% among the smallholder dairy cattle population in Rwanda.

The proposed breeding strategies in the present study are not expected to compromise the level of genetic diversity in the indigenous population. The rate of inbreeding in the indigenous and crossbred populations was low because of systematic genetic improvement using imported sires, replacement of bulls in every generation, and random mating. Nevertheless, caution is recommended when integrating the chosen breeding strategy into prevailing local practices. Some of the latter need to be revised for optimal implementation of the new strategies. Some important current practices that may fall into this category are: (i) many countries in SSA have a limited number of bulls that are kept in AI centres and used for AI service for many years without being replaced; (ii) inseminators and smallholder dairy farmers are inclined towards using the semen from few sires of high yielding breeds such

as Holstein, which are kept in these AI centres; (iii) in areas where AI is limited, a single bull may be used to serve one or two villages for a long period without replacement; (iv) coordinated platforms for systematic pedigree and record keeping of dairy cattle in smallholder systems are generally missing.

5.4.4 Practical implementation

The present cow population in Tanzania is estimated at 7,444,213 million heads of which 7,206,696 are indigenous cows and 237,517 are non-indigenous cows (upgrades and dual purpose) (National Bureau of Statistics (NBS) 2015). The target is to increase improved dairy cattle numbers by about 3.8 times by 2022 (Michael et al. 2018; United Republic of Tanzania (URT) 2019) in order to achieve the overall objective to establish a sustainable and competitive dairy sector. Recently prepared policy documents including Tanzania Livestock Master Plan (Michael et al. 2018) and National Livestock Research Agenda 2020 - 2025 (United Republic of Tanzania (URT) 2019) highlight the importance of the dairy sector in poverty reduction, improved food security and increased national income. Currently, the government, international organisations such as International Livestock Research Institute (ILRI) and Heifer International, and local smallholder dairy farmers are focusing on increasing milk yield with the aim to reduce the production–consumption gap, which, under the current practice, is estimated to increase to 5.8 million litres in 15 years (Michael et al. 2018). This increase will be driven by increasing human population, income and urbanisation. Results from the present study contribute to the implementation of the established livestock policies and government efforts to improve the dairy sector. The potential benefits and practical implementation of using imported purebred exotic, locally available crossbred and indigenous bulls for improving dairy productivity is discussed below.

Results of the present study showed that importation breeding strategy will offer a significant improvement in dairy productivity. Systematic crossbreeding and selection based on farmer preferred traits will lead to an

overall better performance under smallholder production systems compared to establishing a new synthetic breed or improving the indigenous population with domestic selection. The crossbreds will have better performance in terms of milk yield, longevity and temperament. Systematic gradual upgrading will allow time to the foreign genotypes to be adapted to the local conditions. However, this strategy will also result in animals with heavier body weight, hence increased feed uptake, and relatively longer calving intervals, implying compromised fertility. Judging from results from this chapter, the farmer's dairy cattle preferences (Chapter 4), and earlier research undertaken in SSA (Chapter 2), systematic upgrade of the local population based on the importation breeding strategy will have more potential in the cooler highlands zones. It should be emphasised that this type of strategy must be combined with a better level of management of animals across all seasons. The latter is especially important since this breeding strategy might be linked with increased feeding costs.

In Tanzania, semen is currently being collected from randomly imported live bulls (not elite selected bulls) housed at the National Artificial Insemination Centre (NAIC). These bulls are mainly Friesian, Ayrshire and Jersey and sourced from Europe, USA, New Zealand and neighbouring countries in Africa such as Kenya and South Africa. The collected semen is distributed to farmers in various regions of Tanzania by government and private extension officers. Semen selection from NAIC is often done by the inseminators. The current breeding policy is simply based on use of this exotic semen to upgrade the indigenous cattle. The imported sires are expected to be genetically superior due continual improvement in the country of origin of exotic sires; they would be also relevant to Tanzania since selection will be based on the African Overall Farmer Index. A policy document for guiding the use of appropriate semen in different agro-ecological zones needs to be developed to embrace both the relative preference and predicted genetic gains for the individual breeding goal traits. A multilateral agreement between breeding companies in Tanzania and the country of origin of exotic sires should be developed to

ensure the continuous supply of desired sire semen that suits smallholder farmers' breeding goals.

Importation strategies involve the utilisation of both local and imported genetic materials. The choice of the best breeding strategy needs to be further investigated based on the genetic and economic ranking of breeding strategies. Also, further social implications of the proposed breeding strategies need to be examined. For instance importation breeding strategy requires foreign currency for purchasing semen from the country of origin of exotic sires. Because of limited resources and challenging production environments in smallholder farming systems importation breeding strategy in the long term are likely to be more expensive than synthetic breed due to management, health, feed and fertility related costs. Furthermore, in the long run, the importation strategy will also present a threat to indigenous animal diversity. An economic analysis should be carried out to assess the costs and benefit of this strategy. Currently, semen produced by NAIC is subsidised by the government. However, the price for insemination still varies depending on the distance from the NAIC. Careful coordination of semen importation will be important to ensure that semen is imported based on farmer trait preferences in different production environments. In this breeding programme, NAIC is expected to be the lead organisation for semen importation. In the long run, the government through NAIC will need to promote public–private partnership to ensure availability of semen at affordable prices to smallholder farmers. Improvement of AI infrastructure will increase the rate of AI adoption.

Selection and utilisation of crossbred bulls to create a more productive and resilient synthetic breed within the smallholder system is feasible. This breeding strategy was found to be more efficient when the level of exotic genes is maintained at around 50%. Under this strategy, a large number of F1 will be required at the beginning of the breeding programme. The next step will be to select and mate F1 heifers with F1 young bulls to produce F2. Selected sires for each generation will be submitted to NAIC for semen collection.

Farmers in coastal areas put nearly equal emphasis on fertility and milk production (Chawala et al. 2019). Therefore, a new synthetic breed might be suitable in coastal zones characterised by low input production systems because of improved CI and TEMP, and low BWT. Various studies have shown that synthetic breeds or crossbreds with 50 to 75% *Bos taurus* genes are better suited in the challenging environments of the tropics compared to exotics (FAO 2009; Galukunde et al. 2013). Milk production and longevity are expected to increase with increasing proportion of AI to create F1. The coastal selection index predicted a lower genetic progress compared to the overall index. However, the cost and benefit of using synthetic breeds compared to upgrades and/or indigenous need to be quantified to identify the best strategy for the coastal agro-ecological zone. Within each agro-ecological zone, NAIC in collaboration with multinational and local dairy breeding companies will be required to characterise farmers into production systems to identify the most suitable genotype based on animal husbandry practices, feed availability, micro-climate and level of management.

The indigenous cattle improvement strategy based on domestic selection of the best indigenous sires could be adopted as a part of genetic conservation of local cattle breeds. Many African indigenous cattle are considered as endangered and their unique adaptive characteristics may be lost forever due to uncontrolled crossbreeding and/or replacement with exotic genotypes (Mwai et al. 2015). An estimated 32% of the indigenous cattle in Africa have become extinct in the last century and another 22% are in danger of extinction (Rege 1999). Although not competitive to the upgrade/importation and new synthetic breed strategies in terms of animal performance, selection and genetic improvement of indigenous cattle might be attractive to farmers in low input systems who wish to utilise and conserve local breed. This strategy will also contribute to the reduction of genetic erosion of indigenous cattle diversity, which has occurred due to the current indiscriminate crossbreeding programmes that have largely ignored conservation of indigenous genetic resources.

The realisation of any of the studied breeding strategies will depend on a well-established national herd recording scheme. In the first instance, a relatively simple recording scheme of the five preferred traits of the smallholder farmers should be established. A minimum amount of data to be recorded should include animal identity and pedigree, daily milk yield, date of calving, periodic measurement of body weight, lactation number and temperament score. Simple methods for data recording such as use of girth-tape for body weight measurement could be adopted. The genetic and phenotypic progress based on Reduced Farmer Index (LMY and CI) which are the two most important and possibly easiest to record trait was close enough to the Overall Farmer Index to warrant implementation. The Reduced Farmer Index may provide a certain level of progress in the first instance, while the recording platform for the other traits is being developed.

The next priority should be in strengthening AI services including the establishment of liquid nitrogen plants in each agro-ecological zone. It is recommended that a national genetic evaluation service be formed. This service will be responsible for genetically evaluating all bulls, identifying selection candidate, and assessing the genetic progress made over time. The national genetic evaluation service will work closely with the NAIC, government, private extension officers and farmers participating in the programme. A communication strategy will need to be developed to enhance the dissemination of available information for the selected bulls and uptake by the end-users (farmers). This strategy should include periodic feedback to farmers on the performance of bulls, and aim to specifically address farmer's needs. In this way, decisions on appropriate breeding strategies will be implemented based on what the breeding companies know and what farmers want or need.

5.5 Conclusions

Results of the present study demonstrated that upgrade of indigenous cattle through systematic importation of appropriate exotic genetic material would lead to an overall higher genetic progress in the dairy population in sub-Saharan Africa compared to developing a new synthetic breed or improving the indigenous breeds with domestic selection. Selection and importation of exotic sire semen should be based on the African Overall Farmer Index of preferred traits identified by smallholder dairy farmers. Separate selection indexes should be derived based on animal trait preferences within agro-ecological zones. This would optimise the improvement of dairy cattle performance in the prevailing smallholder farming systems in sub-Saharan Africa. Increasing the proportion of cows participating in the genetic improvement programme would result in additional benefits. The results from this Chapter provide an opportunity for breeding programme designers to choose the appropriate breeding strategy that fits a particular production environment.

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5.6 Chapter appendices

Appendix I:

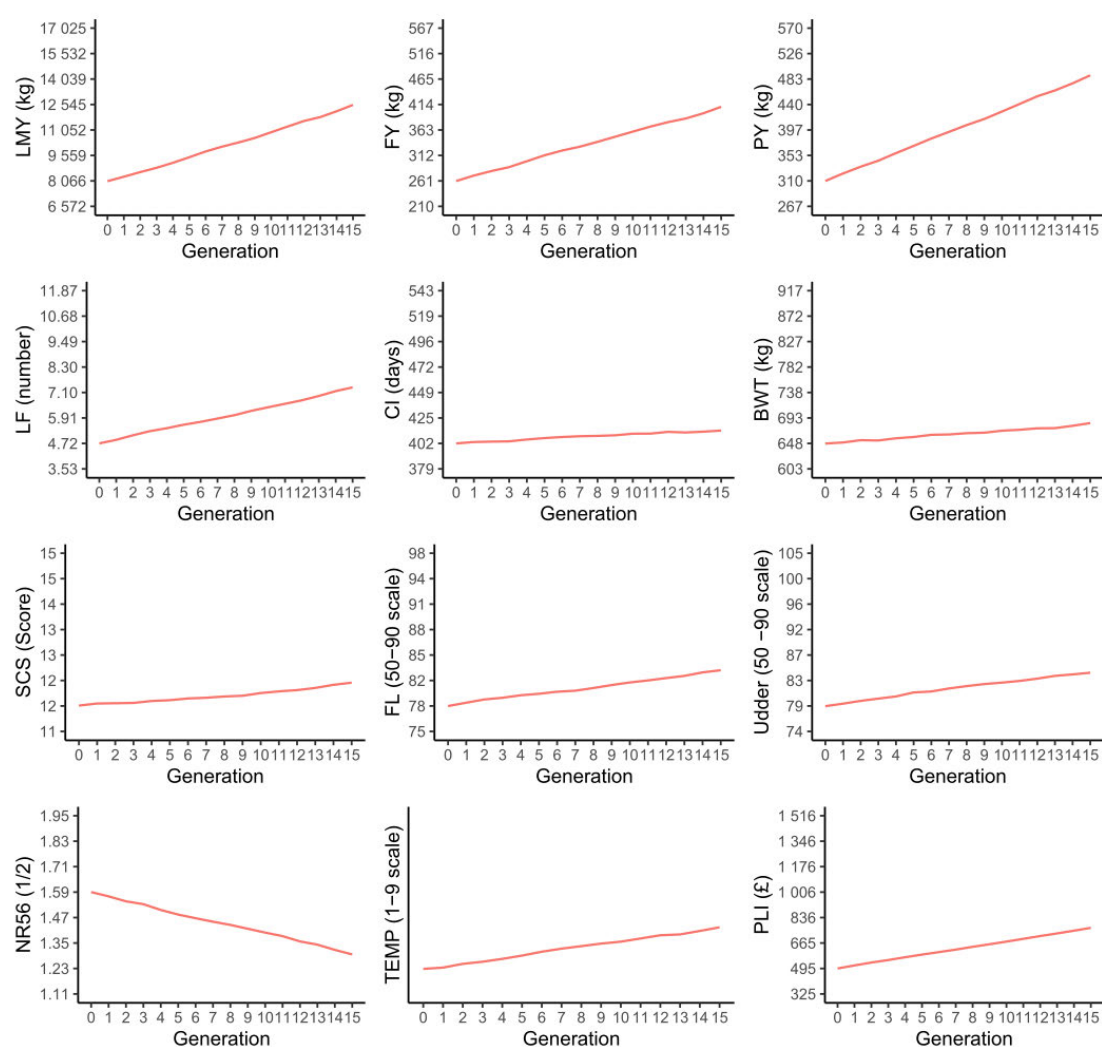
Table 1 Estimates of heterosis and recombination loss for breeding goal traits in smallholder dairy production systems

Trait	Maximum heterosis for F1 (%)	Parental Mean	Maximum heterosis for F1	Exotic breeds in Africa	Indigenous breeds
LMY (kg)	35%	2,706.50	947.28	4,050.00	1,363.00
CI (days)	12%	456.00	-54.72	462.00	450.00
BWT (kg)	12%	447.00	53.64	557.00	337.00
LF (No. of lactations)	35%	2.69	0.94	2.68	2.70
TEMP (Score)	0.0%	4.70	0	4.70	4.70
Trait	Maximum recombination loss for F1 (%)	Parental Mean	Maximum recombination loss for F1	Exotic breeds in Africa	Indigenous breeds in Africa
LMY (kg)	40.7%	2,706.50	-1,100.44	4,050.00	1,363.00
CI (days)	3.5%	456.00	15.91	462.00	450.00
BWT (kg)	18.2%	447.00	-81.38	557.00	337.00
LF (No. of lactations)	15.6%	2.69	-0.42	2.68	2.70
TEMP (Score)	0.0%	4.70	0	4.70	4.70

Source: Bunning et al. 2018, Birhanu et al. 2015, Demeke et al. 2004, Sharma et al. 2000

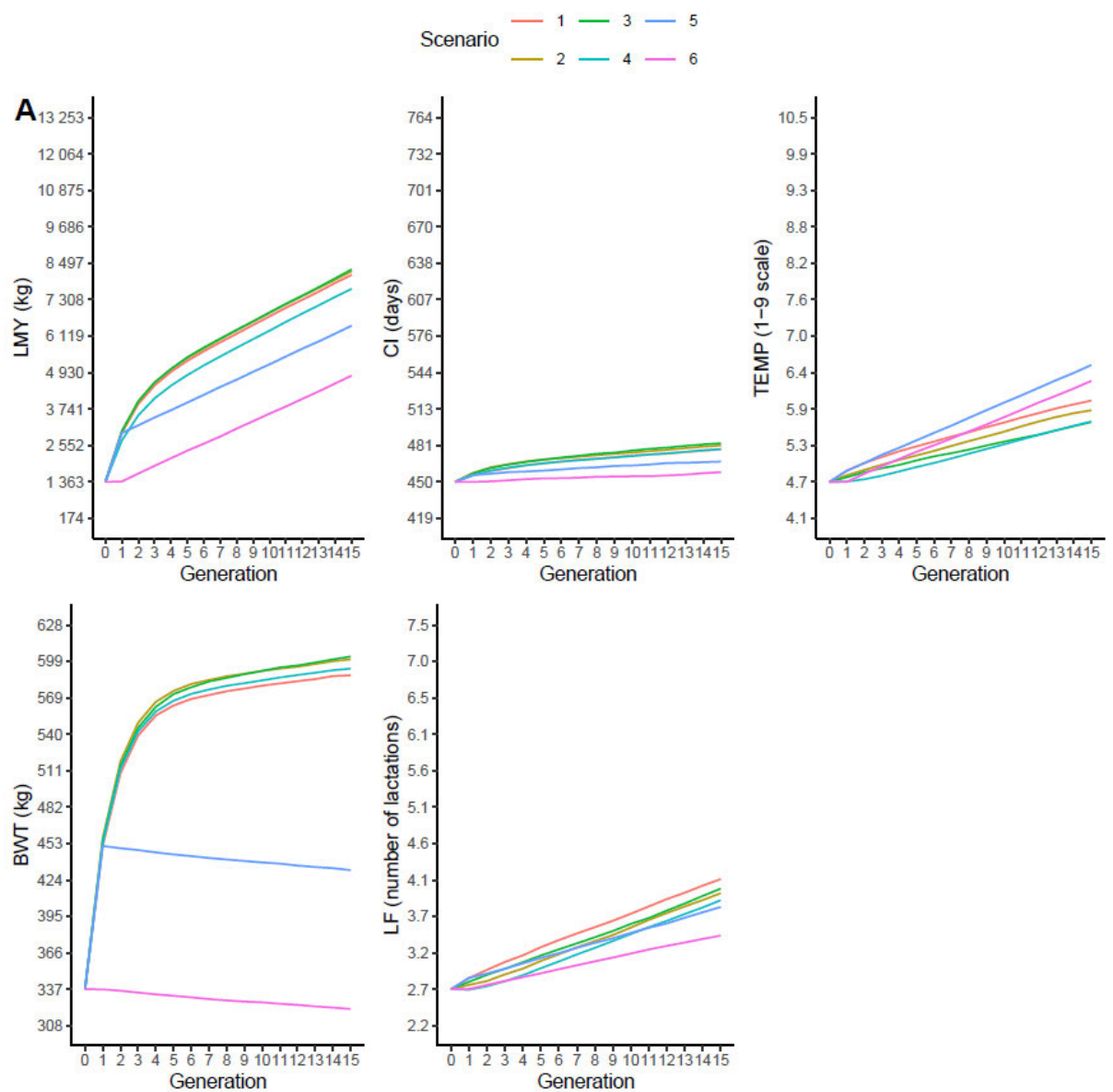
Appendix II:

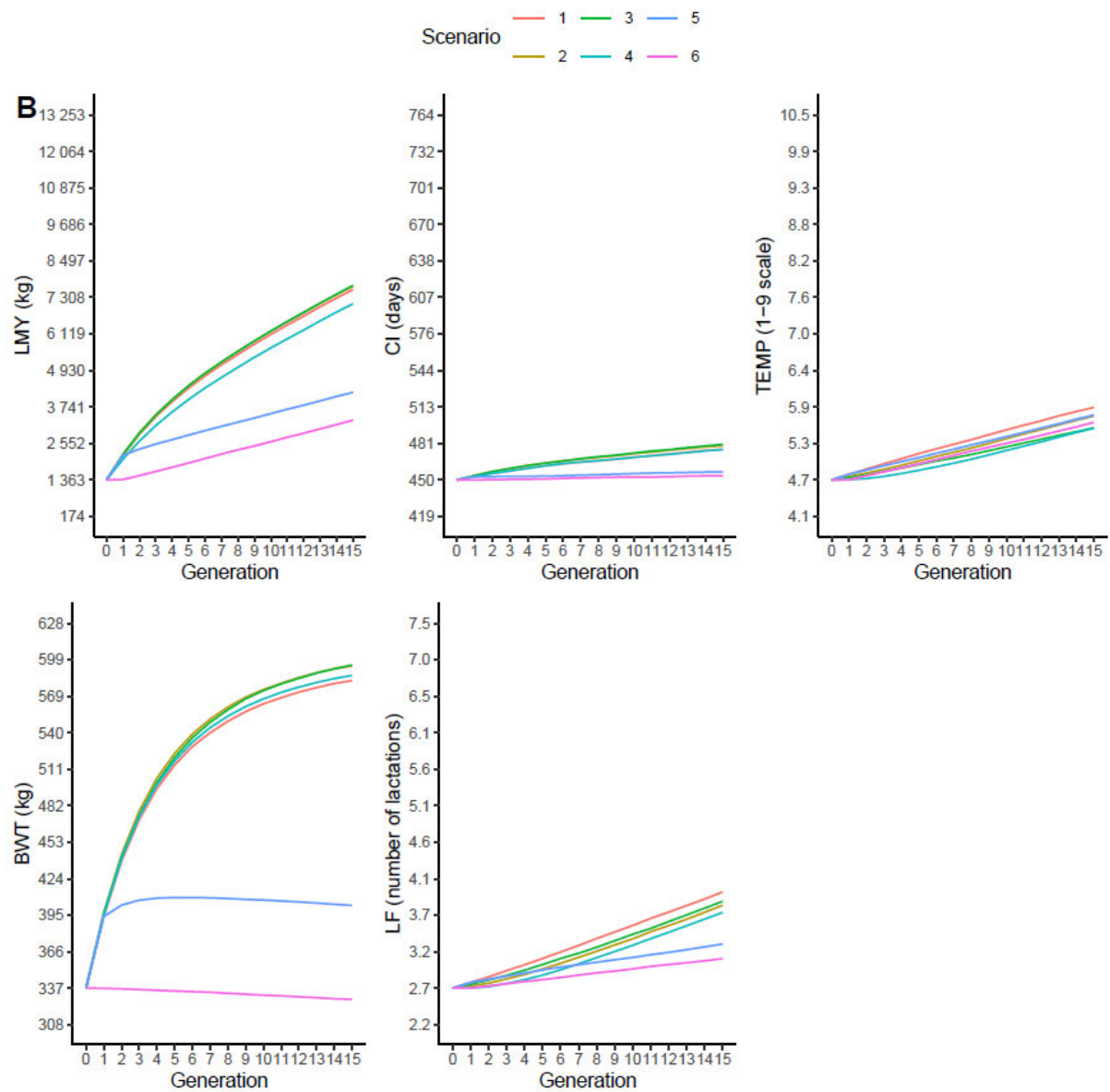
Figure 1 Predicted genetic trends for individual animal traits in country of origin of exotic sires after 15 generation of selection based on the Exotic Index: LMY= milk yield (kg) in a 305 day lactation; Fat = Fat yield (kg) in a 305 day lactation, Protein = Protein yield (kg) in a 305 day lactation, LF = longevity (number of lactations), CI = calving interval (days), BWT = mature live body weight (kg), SCS = Log-transformed somatic cell count score, Feet= Composite of linear type traits related to legs and feet (50-90 scale), Udder = Composite of linear type traits related to udder (50-90 scale), NR56 = Non-return to service (1=returned to service, 2=conceived and did not return to service), TEMP = temperament score (1-9 scale).

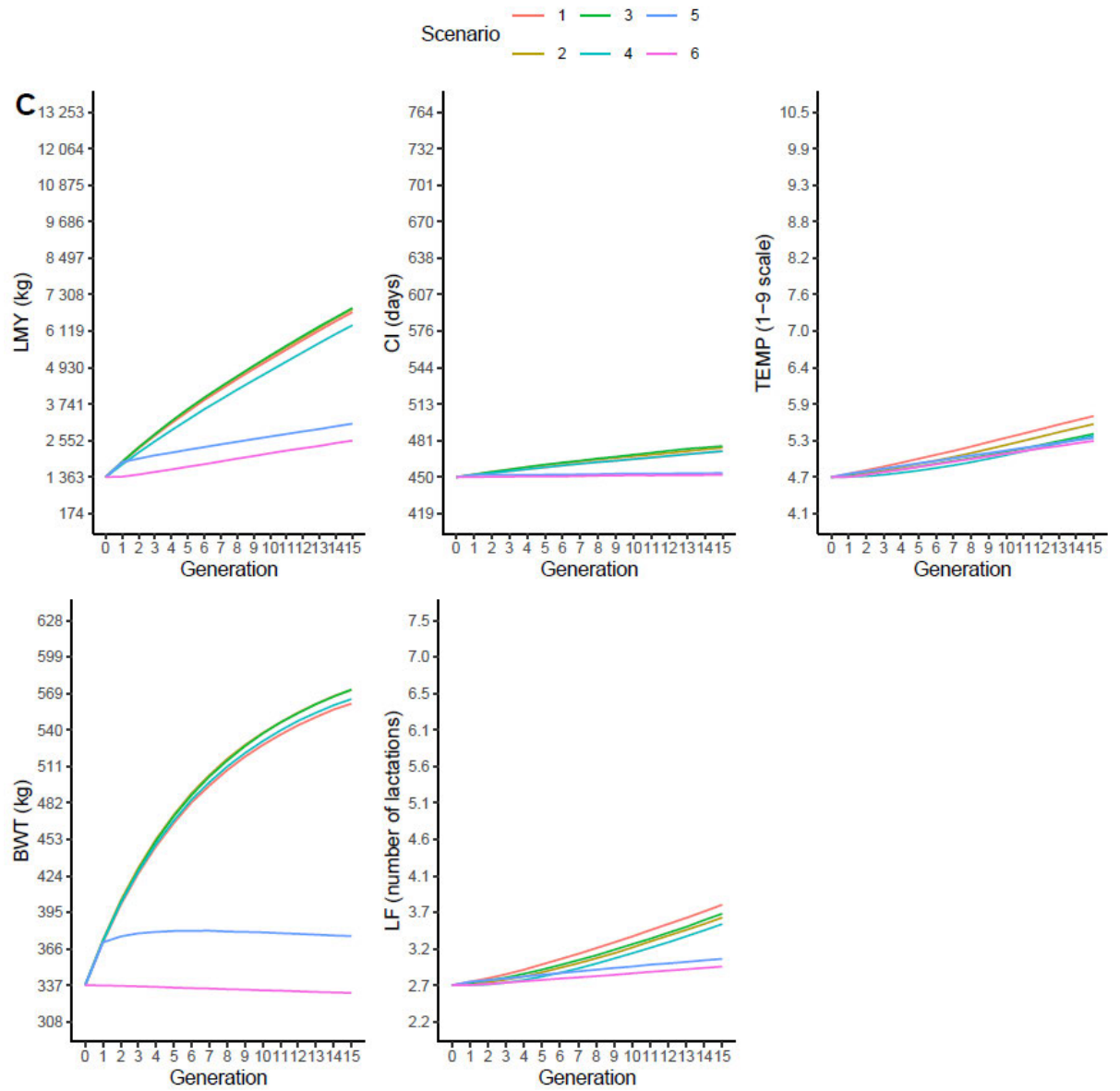


Appendix II:

Figure 2 A, B and C Predicted genetic trends for individual animal traits in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes: LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).







Appendix III:

Table 1 Average predicted rate of genetic gain per generation from generation 0 to 5. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

AI-scheme	Scenario	LMY (kg)	CI (days)	BWT (kg)	LF (No. lactations)	Temp (1-9 scale)
100%	Scenario1	753.6	3.10	42.13	0.11	0.11
	Scenario2	770.0	3.70	44.20	0.07	0.08
	Scenario3	773.9	3.65	43.65	0.07	0.07
	Scenario4	668.3	3.09	42.73	0.06	0.05
	Scenario5	439.9	1.69	14.91	0.08	0.13
	Scenario6	217.0	0.65	-1.10	0.04	0.10
50%	Scenario1	594.6	2.44	35.10	0.08	0.08
	Scenario2	609.4	2.90	36.89	0.05	0.06
	Scenario3	609.1	2.86	36.16	0.05	0.05
	Scenario4	521.4	2.41	35.72	0.03	0.03
	Scenario5	255.9	0.48	11.71	0.05	0.07
	Scenario6	115.6	0.17	-0.46	0.02	0.05
30%	Scenario1	427.3	1.70	25.75	0.05	0.06
	Scenario2	438.7	2.08	27.05	0.03	0.04
	Scenario3	443.6	2.13	26.81	0.03	0.03
	Scenario4	373.6	1.69	26.12	0.02	0.02
	Scenario5	155.3	0.30	6.98	0.02	0.04
	Scenario6	69.6	0.10	-0.35	0.01	0.03

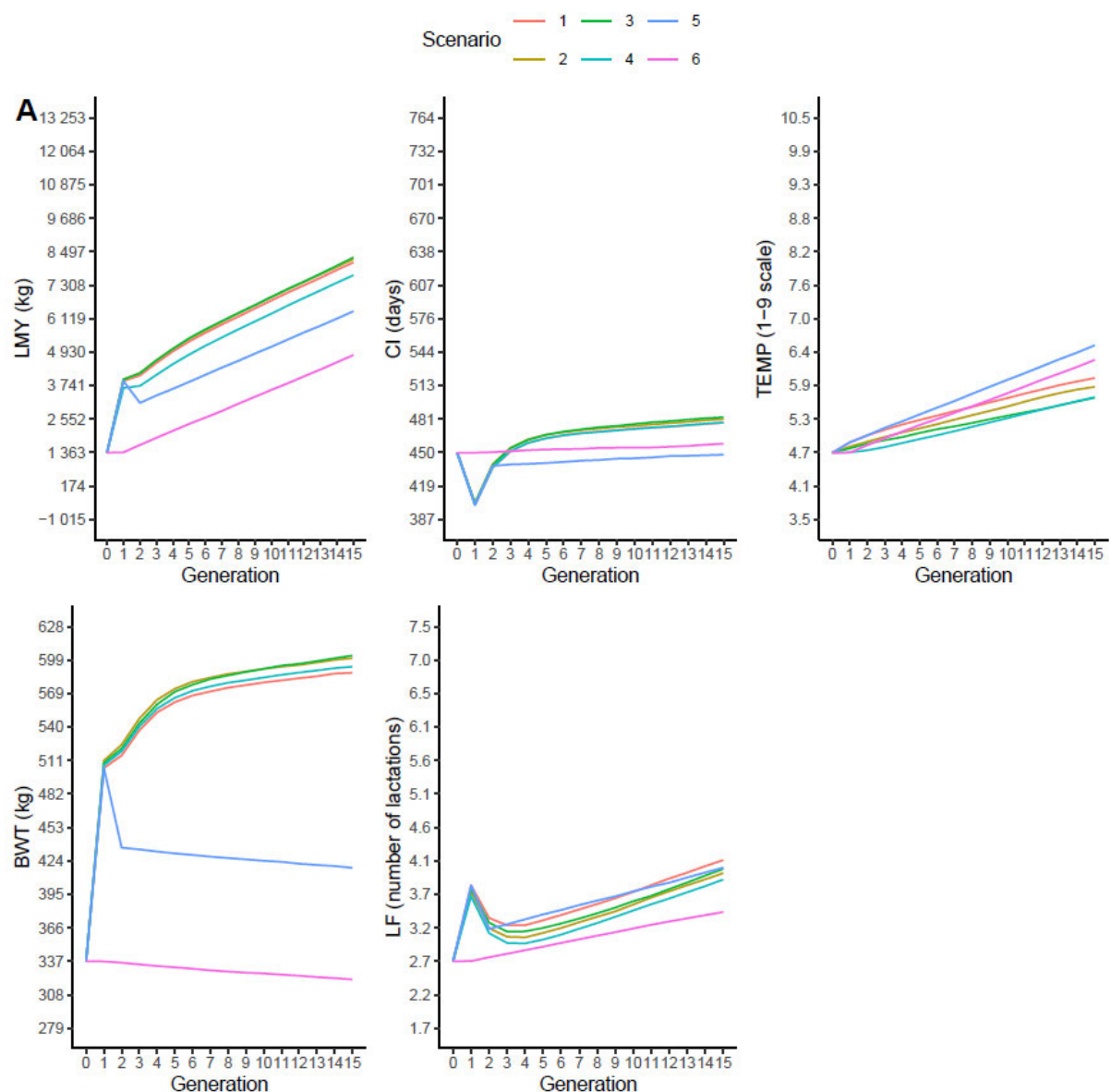
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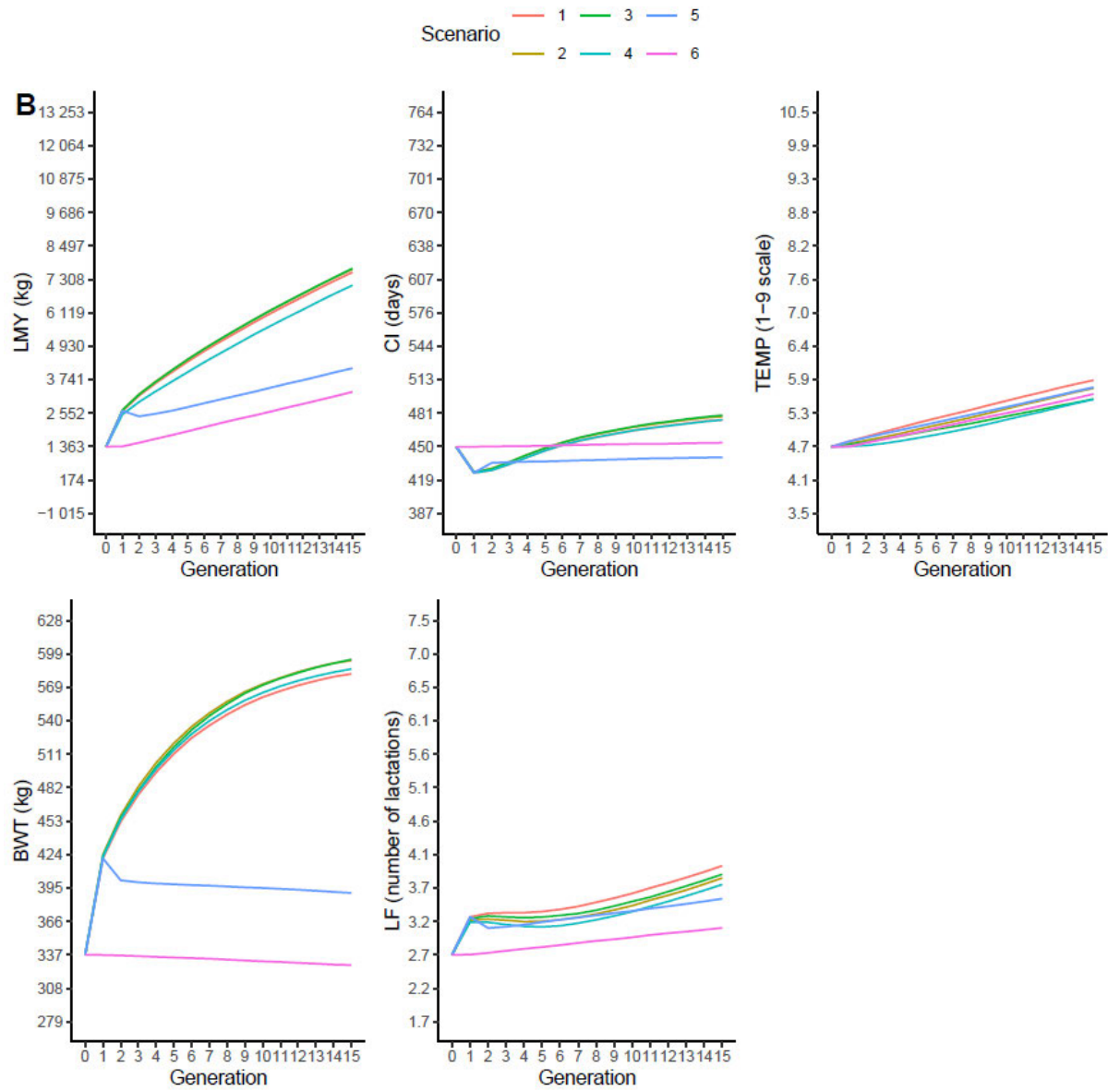
Table 2 Average predicted rate of genetic gain per generation from generation 6 to 15. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

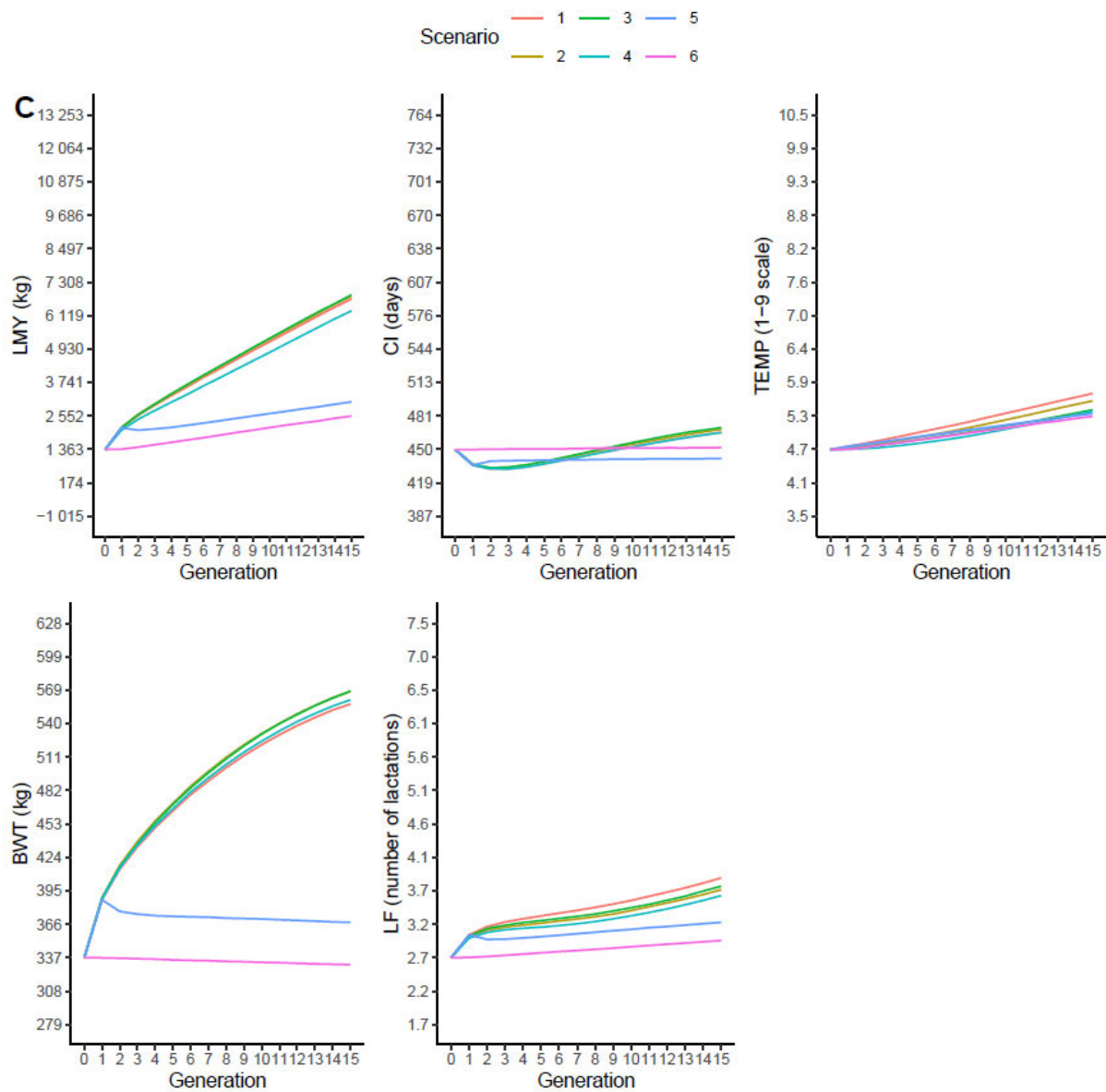
AI-scheme	Scenario	LMY (kg)	CI (days)	BWT (kg)	LF (No. lactations)	Temp (1-9 scale)
100%	Scenario1	276.3	1.15	2.01	0.09	0.07
	Scenario2	278.7	1.22	2.12	0.09	0.07
	Scenario3	281.6	1.38	2.60	0.09	0.06
	Scenario4	277.7	1.20	2.20	0.09	0.07
	Scenario5	249.8	0.76	-1.21	0.07	0.12
	Scenario6	246.0	0.52	-0.99	0.05	0.11
50%	Scenario1	311.1	1.41	5.64	0.09	0.07
	Scenario2	313.8	1.47	5.80	0.08	0.07
	Scenario3	316.6	1.58	6.17	0.08	0.06
	Scenario4	303.7	1.35	5.67	0.08	0.07
	Scenario5	138.8	0.37	-0.70	0.03	0.07
	Scenario6	138.1	0.24	-0.69	0.03	0.06
30%	Scenario1	317.7	1.35	8.64	0.08	0.07
	Scenario2	321.1	1.45	9.00	0.07	0.06
	Scenario3	324.4	1.61	9.18	0.07	0.05
	Scenario4	304.3	1.36	8.79	0.07	0.06
	Scenario5	84.2	0.13	-0.50	0.02	0.04
	Scenario6	85.0	0.12	-0.43	0.02	0.04

Appendix IV:

Figure 1 A, B and C Predicted phenotypic trends for individual animal traits at 100% (A), 50% (B) and 30% (C) AI schemes. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

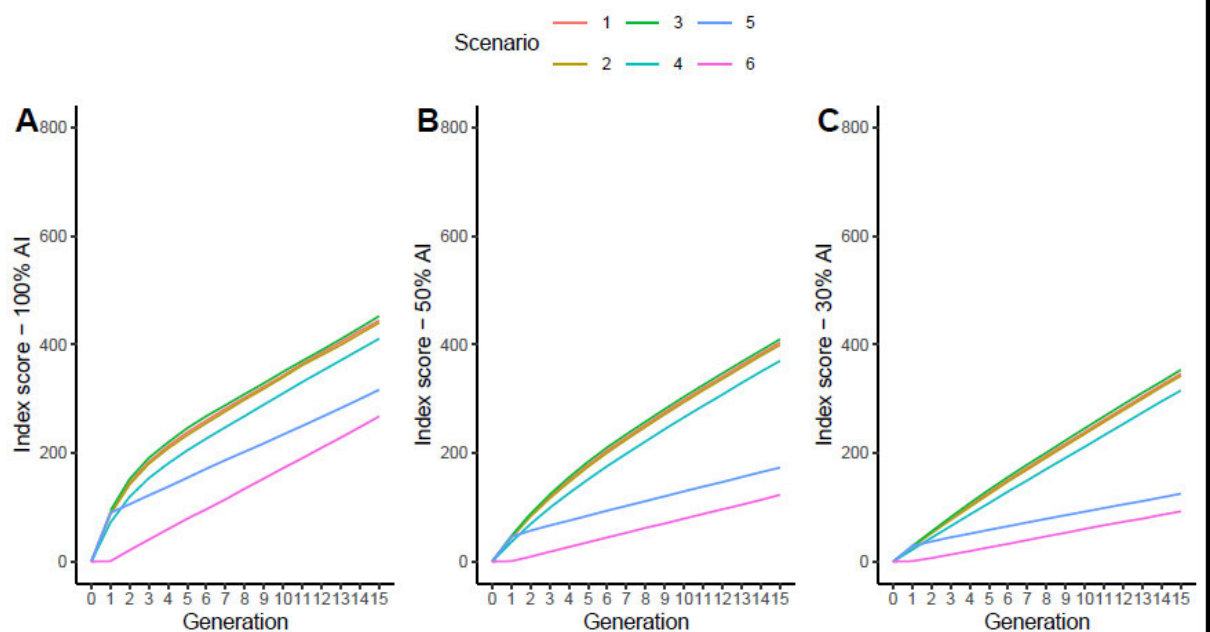






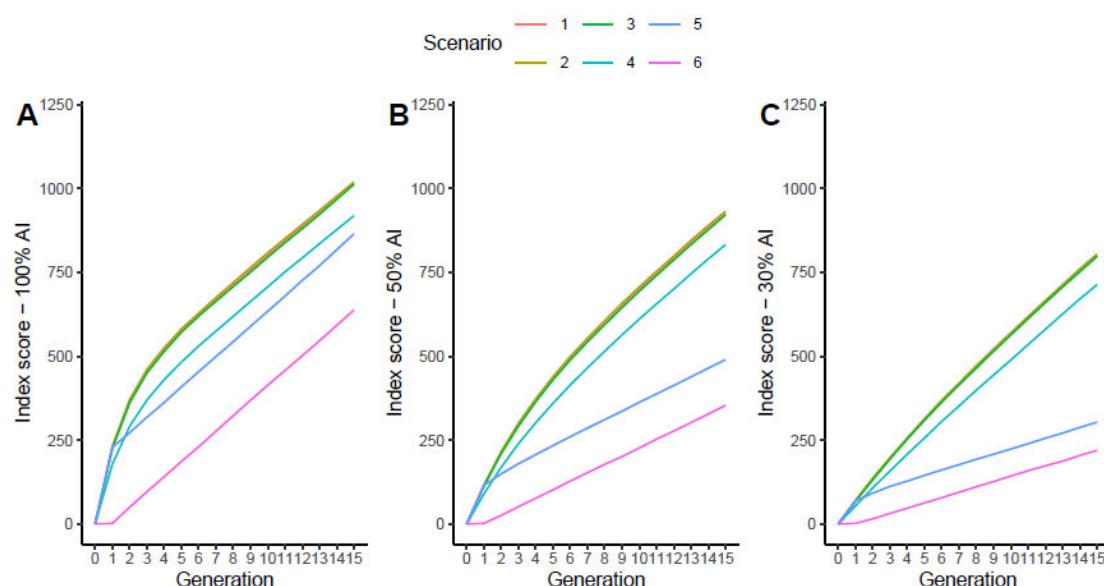
Appendix V:

Figure 1 A, B and C Predicted genetic trends in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when selection was based on the coastal farmer index. Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).



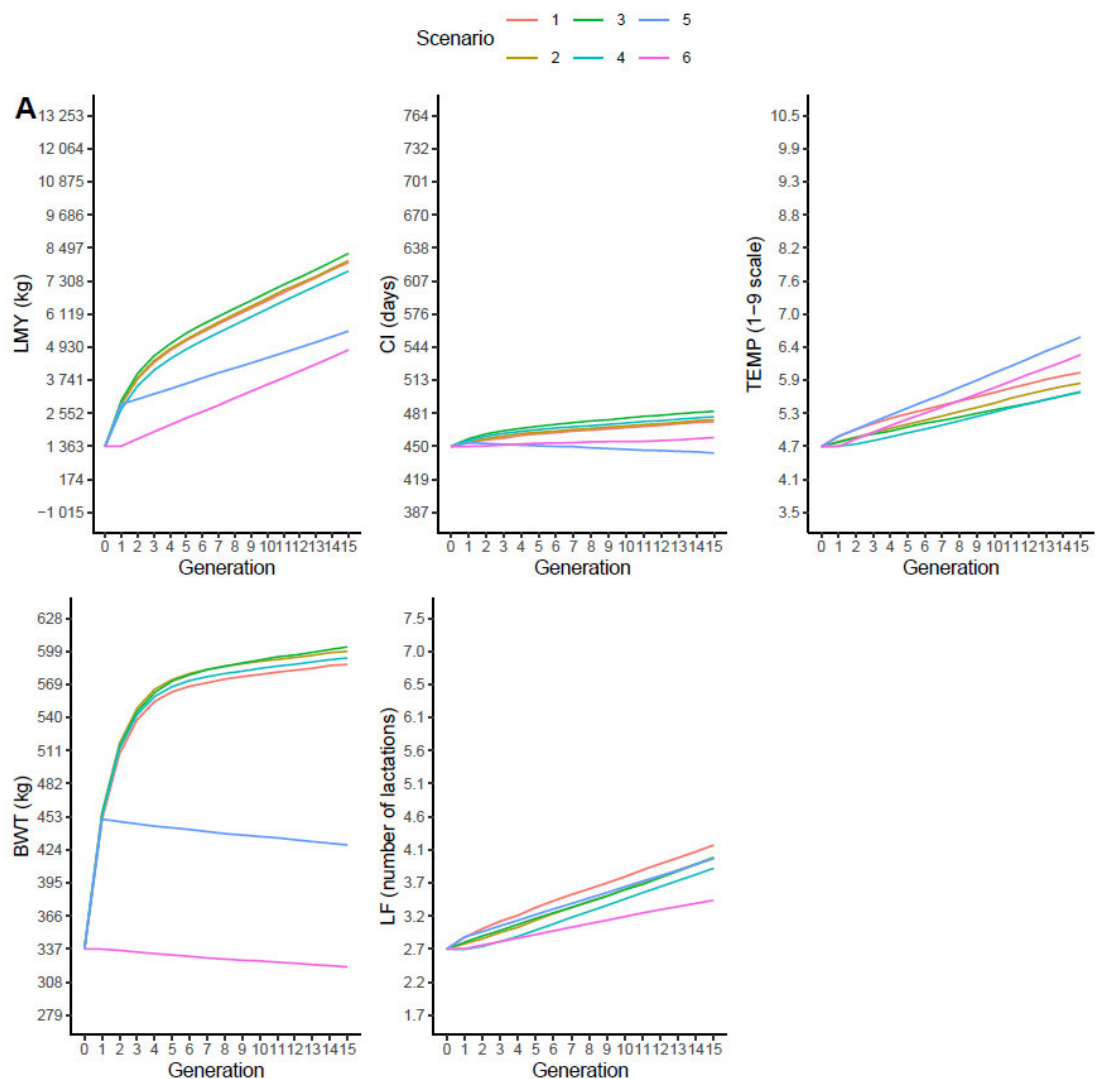
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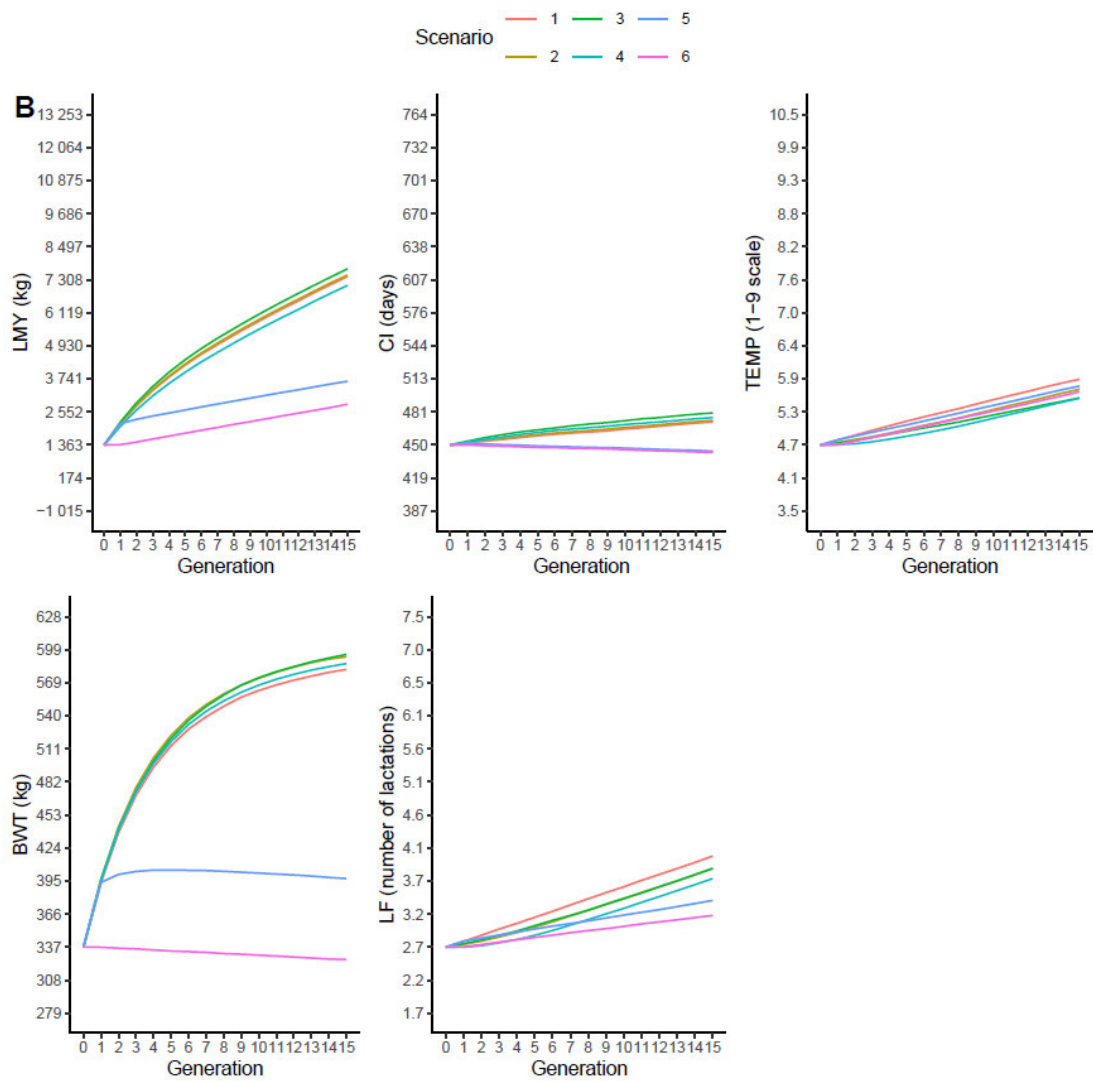
Figure 2 A, B and C Predicted genetic trends in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when selection was based on the highland farmer index. Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

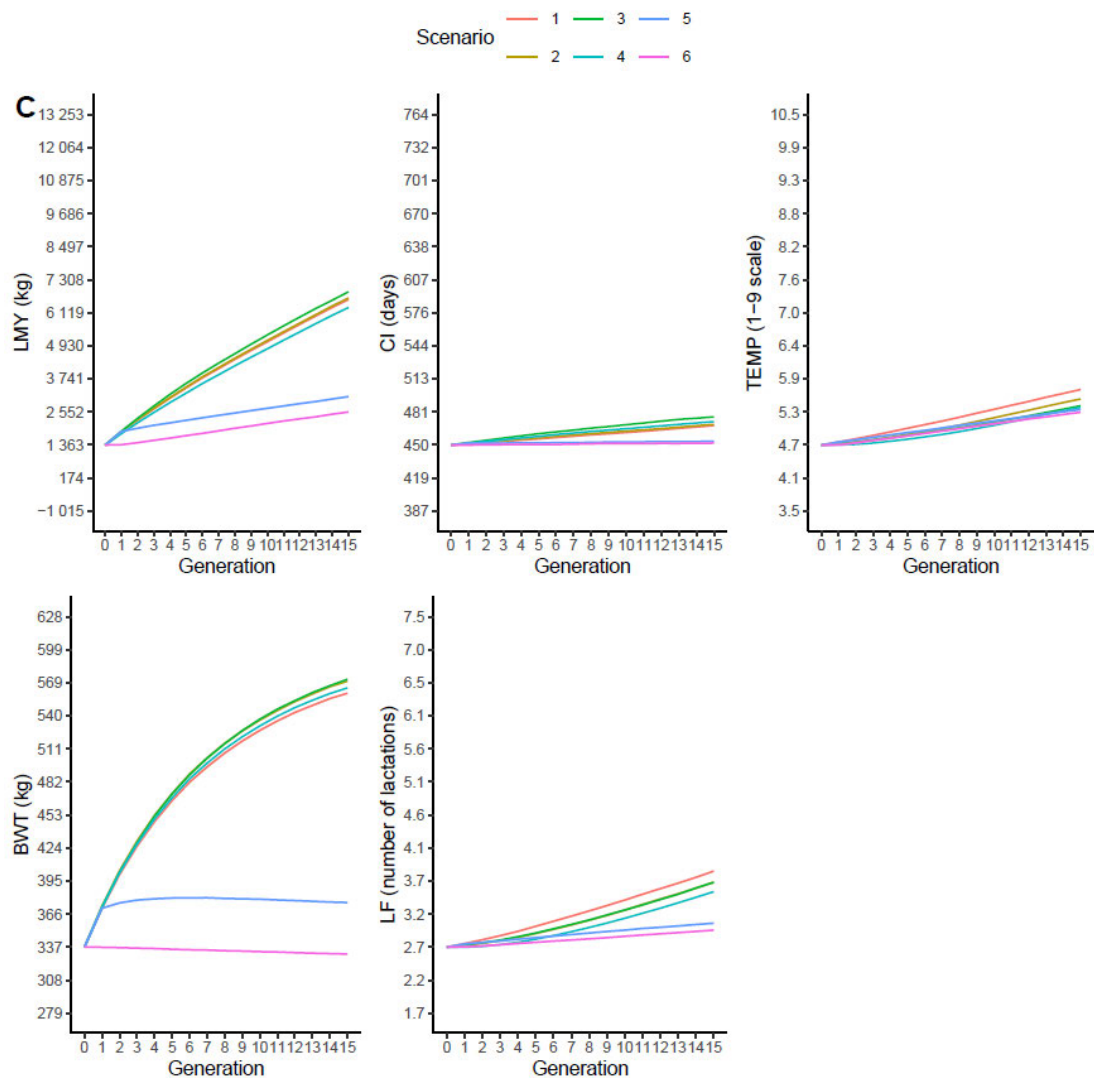


Appendix V:

Figure 3 A, B and C Predicted genetic trends for individual animal traits in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when selection was based on the coastal farmer index. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

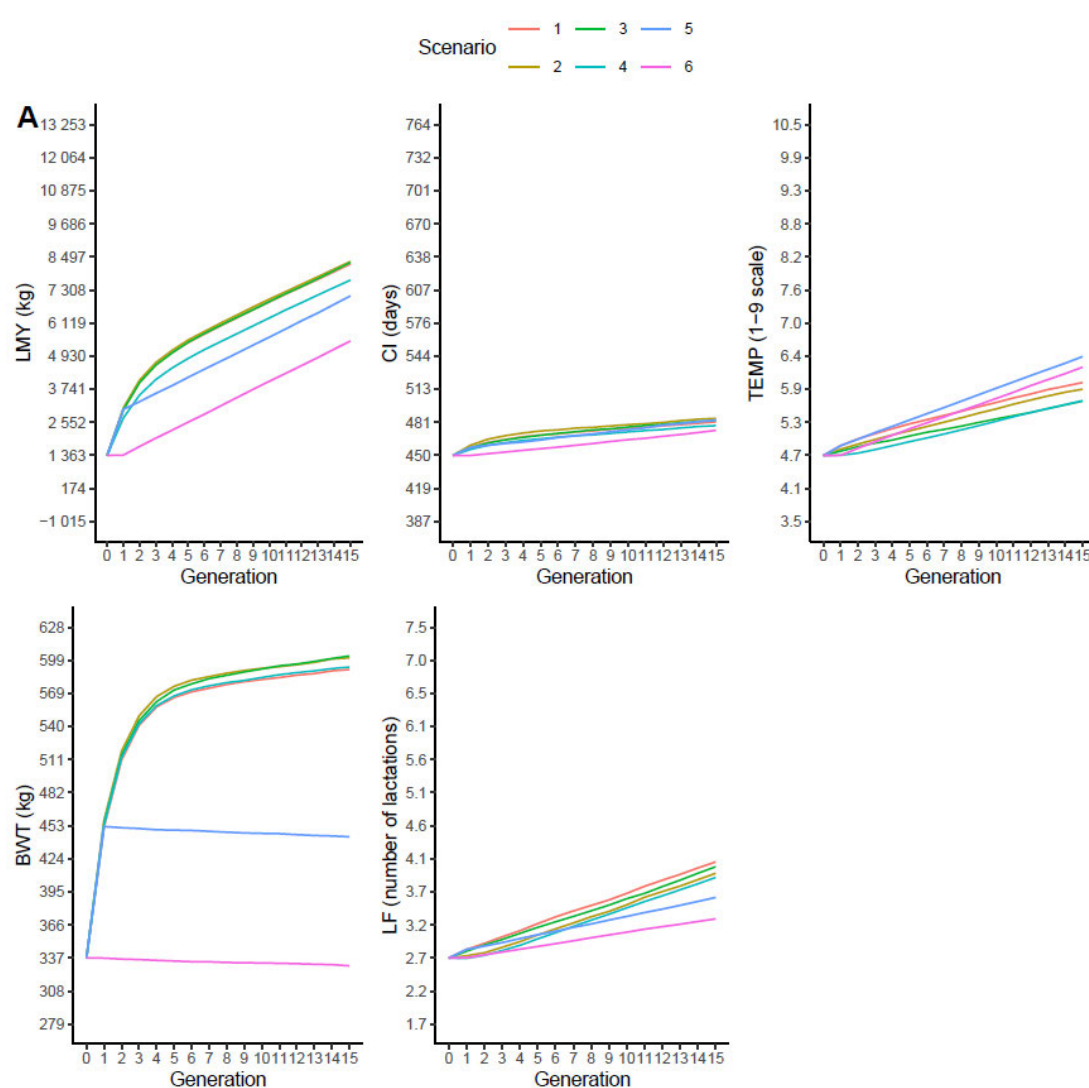


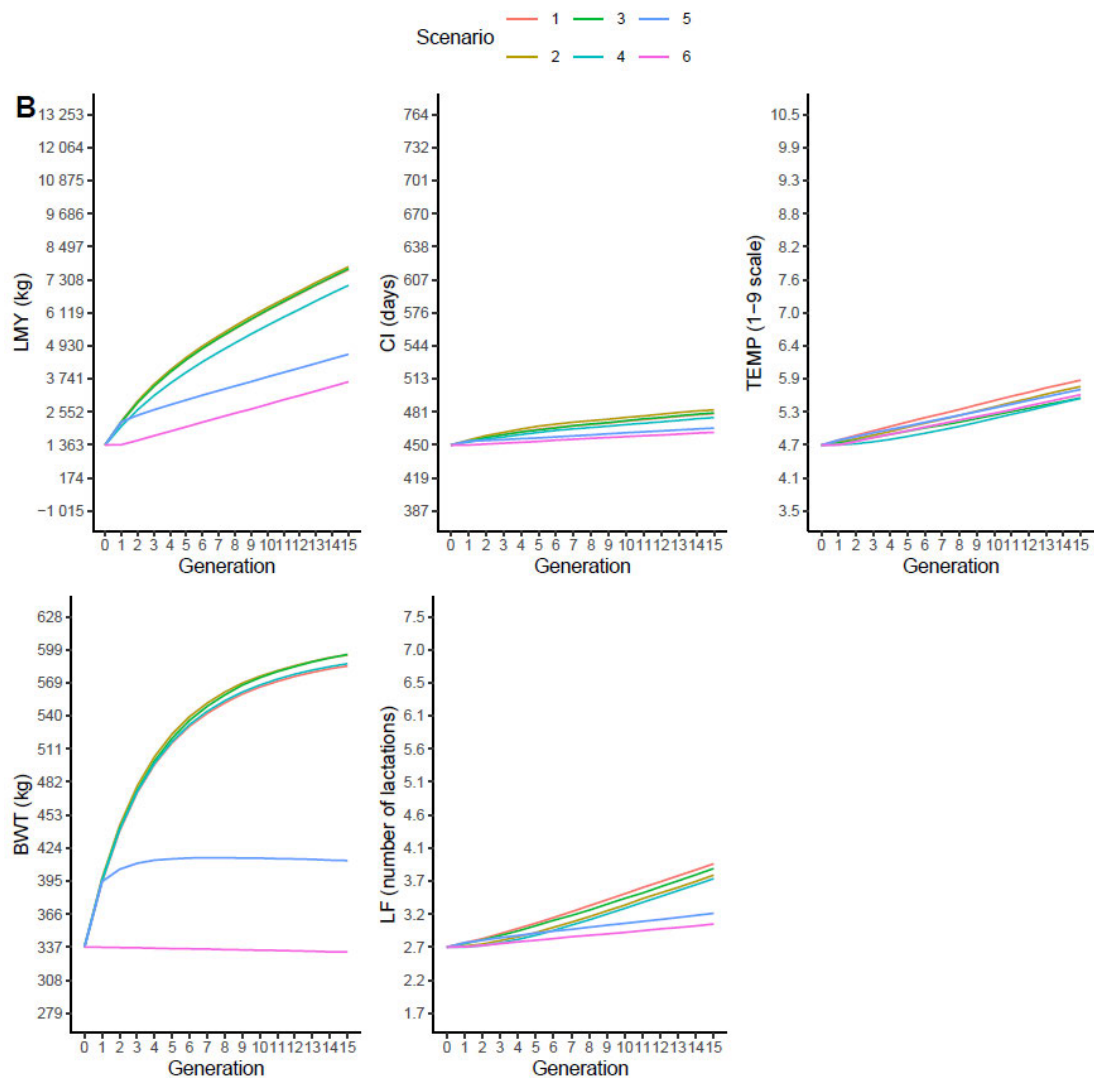


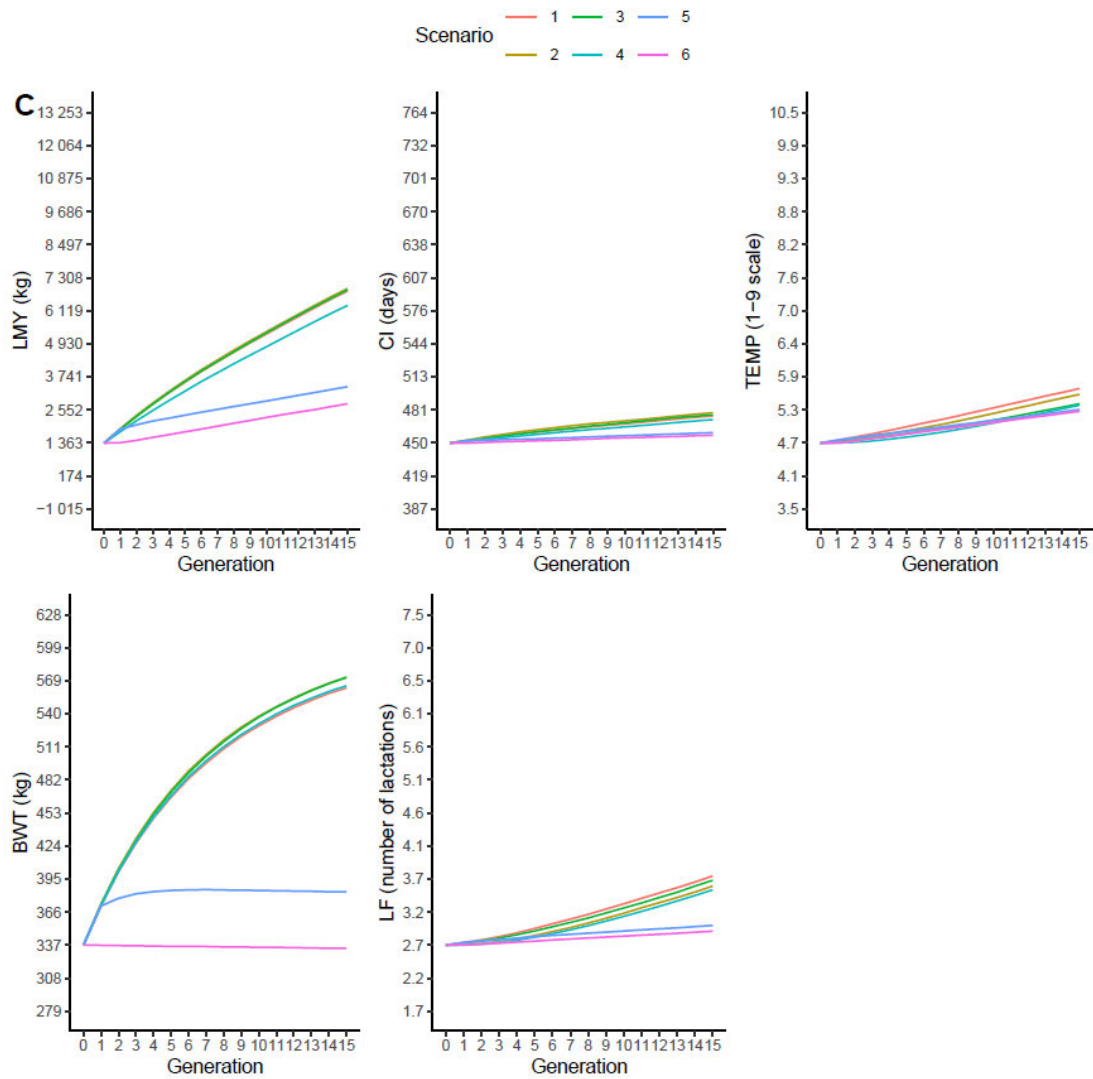


Appendix V:

Figure 4 A, B and C Predicted genetic trends for individual animal traits in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when selection was based on the highland farmer index. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).







Appendix V:

Table 1 Relative differences (%) in predicted genetic gain after 15 generations of selection based on the Farmer Index in the highland and coastal zones between Scenarios 1 (Importation strategy), 5 (Synthetic breed strategy) and 6 (Indigenous breed improvement strategy). LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations).

Difference (%)								
Zone	AI-Scheme	Scenario comparison	LMY	CI	BWT	LF	TEMP	Farmer Index
Highland	100%	1vs5	13.95%	-0.34%	24.89%	12.60%	-7.62%	14.66%
	50%	1vs5	39.71%	2.86%	29.28%	18.39%	2.81%	47.02%
	30%	1vs5	50.44%	3.35%	31.83%	19.40%	6.54%	61.99
	100%	1vs6	33.60%	1.69%	44.09%	20.19%	-4.50%	37.07%
	50%	1vs6	52.61%	3.71%	43.01%	22.38%	4.37%	61.74%
	30%	1vs6	59.40%	3.86%	40.66%	21.66%	7.07%	72.47%
	100%	1vs5	30.95%	6.34%	27.02%	4.61%	-10.36%	28.72%
	50%	1vs5	50.77%	5.88%	31.64%	16.04%	2.05%	57.11%
	30%	1vs5	52.97%	3.19%	32.85%	19.89%	6.20%	63.86%
Coastal	100%	1vs6	39.44%	3.22%	45.27%	19.03%	-5.20%	39.78%
	50%	1vs6	61.86%	6.14%	43.89%	21.43%	3.75%	69.47%
	30%	1vs6	61.35%	3.55%	40.93%	22.54%	7.03%	73.27%

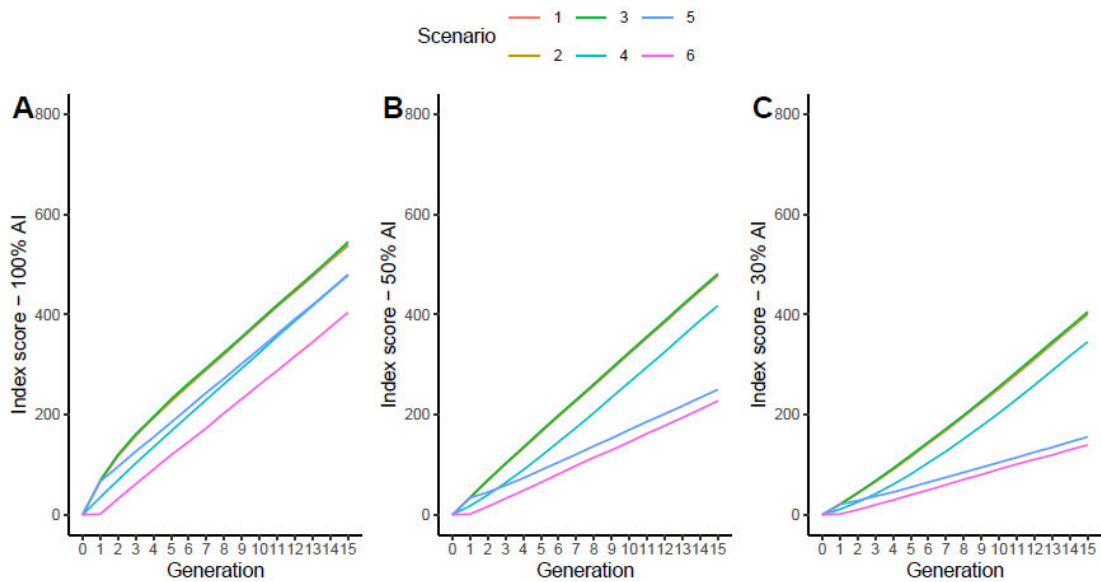
Appendix VI:

Table 1 Relative differences (%) in predicted genetic gain after 15 generations of selection based on the Overall Farmer Index across and within agro-ecological zone between Scenarios 1 (Importation strategy), 5 (Synthetic breed strategy) and 6 (Indigenous breed improvement strategy); performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations).

Zone	AI-Scheme	Scenario comparison	Difference (%)					Overall Farmer Index
			LMY	CI	BWT	LF	TEMP	
Across zones	100%	1vs5	16.22%	11.57%	29.23%	0.79%	-24.35%	10.70%
	50%	1vs5	43.63%	18.87%	40.91%	7.04%	-16.33%	47.59%
	30%	1vs5	51.61%	19.21%	41.63%	6.84%	-13.13%	61.11%
	100%	1vs6	32.02%	22.89%	51.73%	1.85%	-31.60%	24.74%
	50%	1vs6	49.59%	23.24%	50.20%	6.28%	-20.26%	52.35%
	30%	1vs6	56.12%	21.88%	47.68%	6.13%	-15.30%	65.18%
Highland	100%	1vs5	9.34%	9.27%	27.98%	5.61%	-21.71%	5.93%
	50%	1vs5	39.07%	17.12%	38.85%	7.67%	-14.98%	44.62%
	30%	1vs5	48.29%	18.28%	40.48%	7.19%	-12.01%	58.91%
	100%	1vs6	23.85%	20.49%	50.72%	4.52%	-29.95%	19.86%
	50%	1vs6	45.84%	22.21%	49.94%	6.22%	-19.26%	50.97%
	30%	1vs6	53.56%	21.23%	47.53%	5.42%	-14.39%	64.35%
Coast	100%	1vs5	28.18%	14.94%	29.71%	-4.14%	-25.47%	19.75%
	50%	1vs5	50.67%	20.77%	42.62%	6.62%	-17.27%	52.09%
	30%	1vs5	55.86%	20.03%	42.40%	6.88%	-13.08%	63.51%
	100%	1vs6	42.03%	25.57%	52.11%	-0.68%	-33.40%	28.39%
	50%	1vs6	55.93%	24.50%	50.45%	5.71%	-20.65%	54.97%
	30%	1vs6	59.85%	22.53%	47.72%	5.83%	-15.43%	65.84%

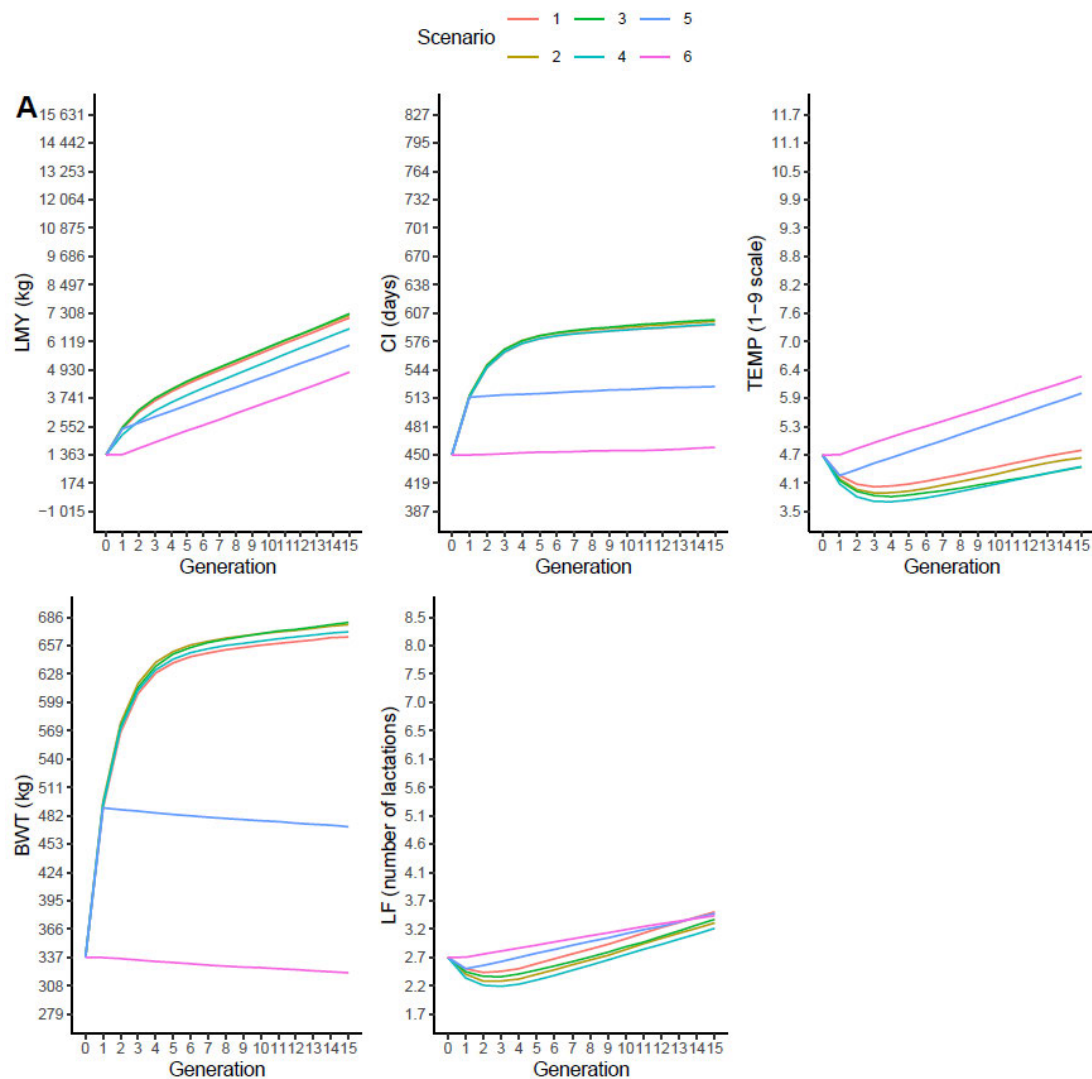
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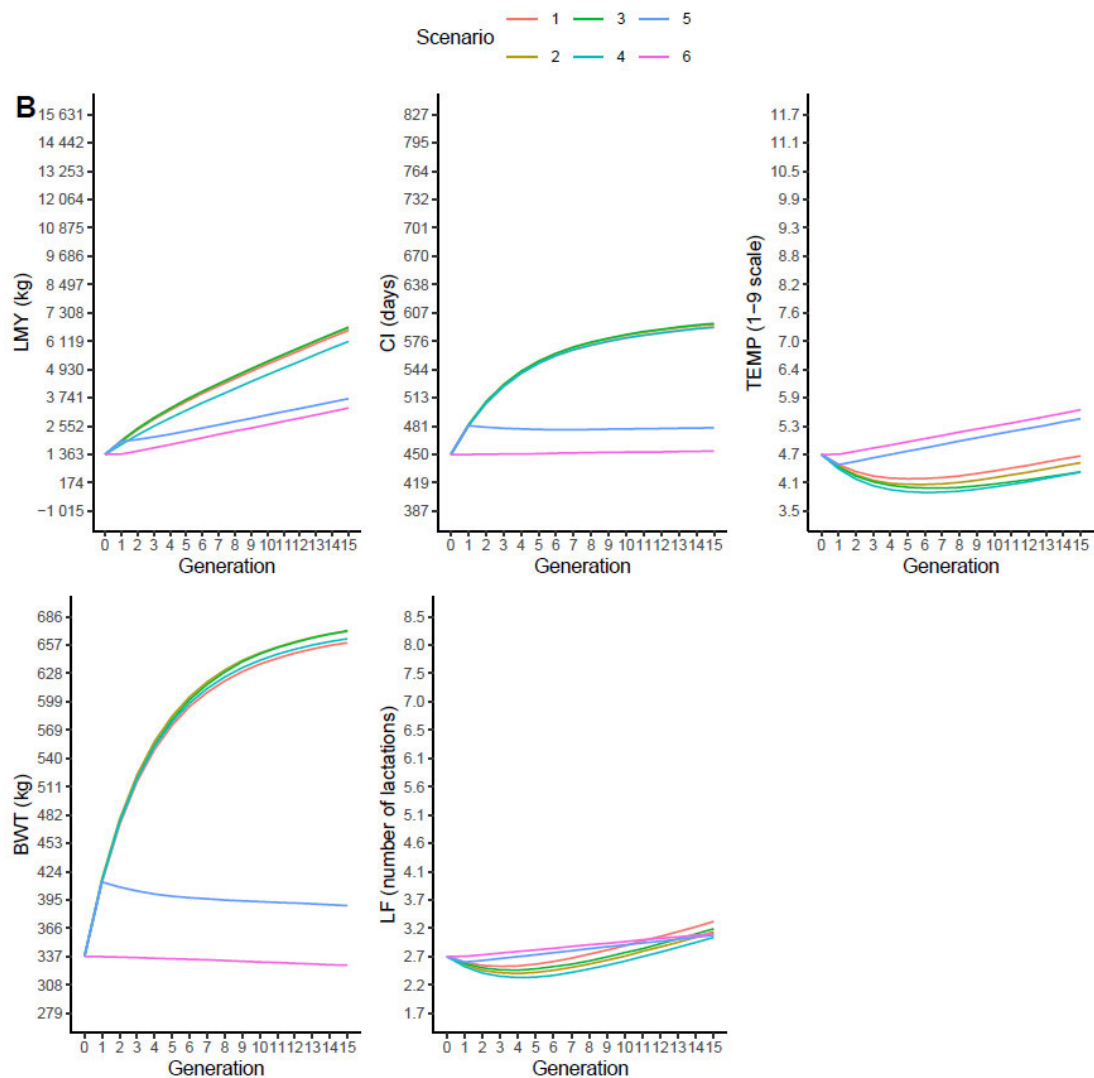
Figure 1 A, B and C Predicted genetic trends in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design. Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

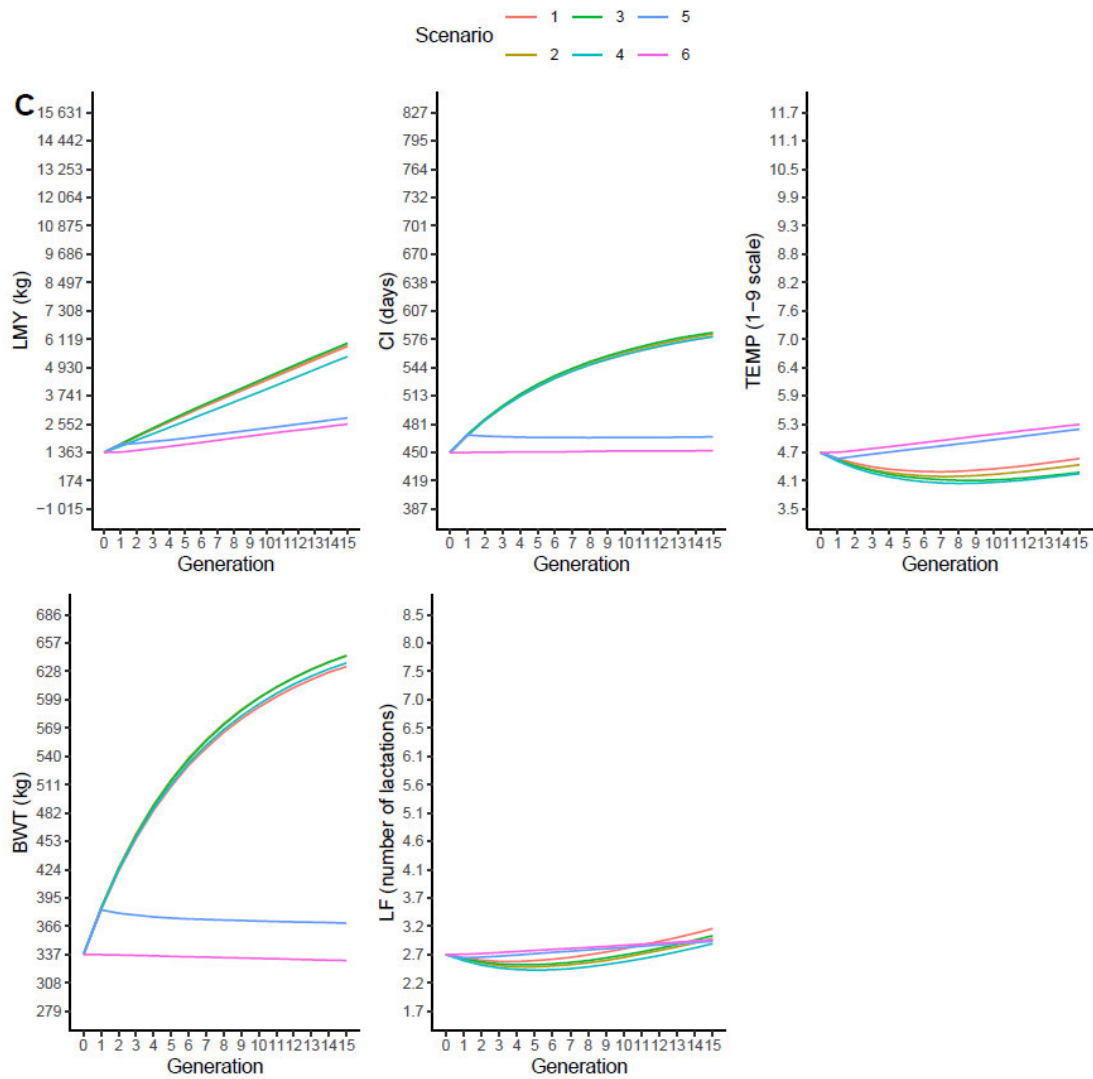


Appendix VI:

Figure 2 A, B and C Predicted genetic trends for individual animal traits in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

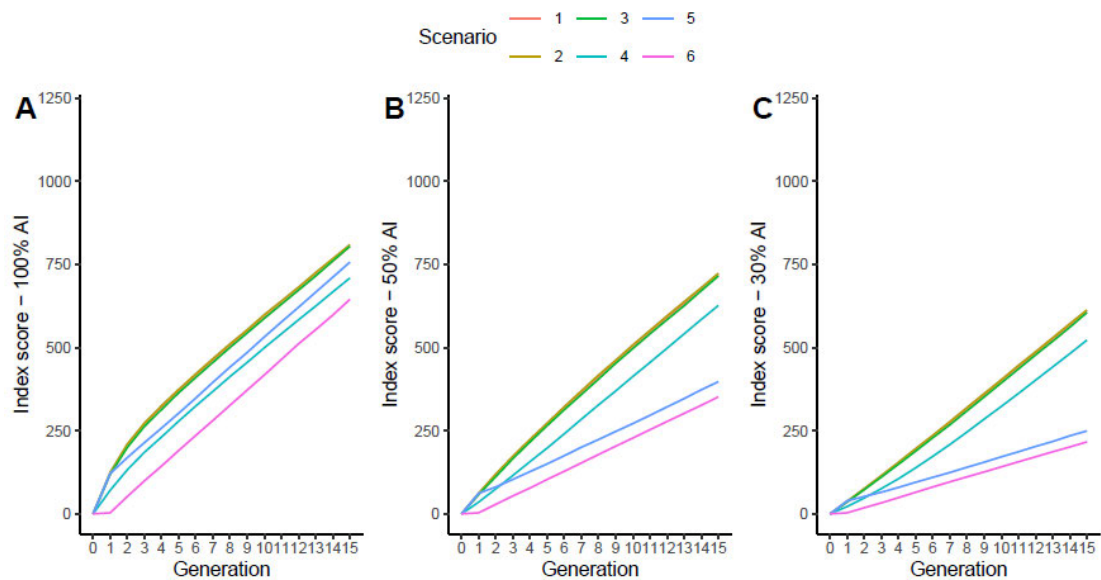






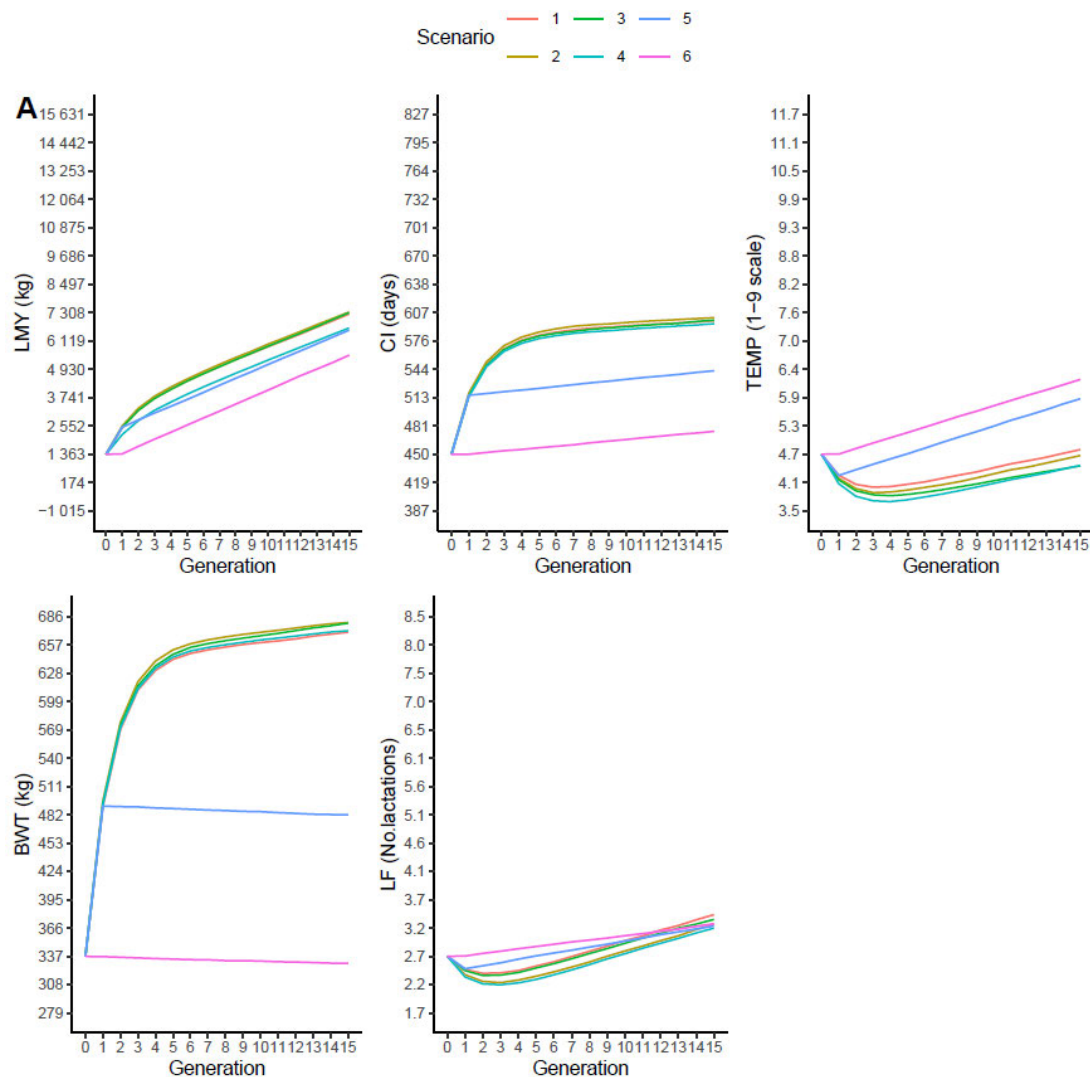
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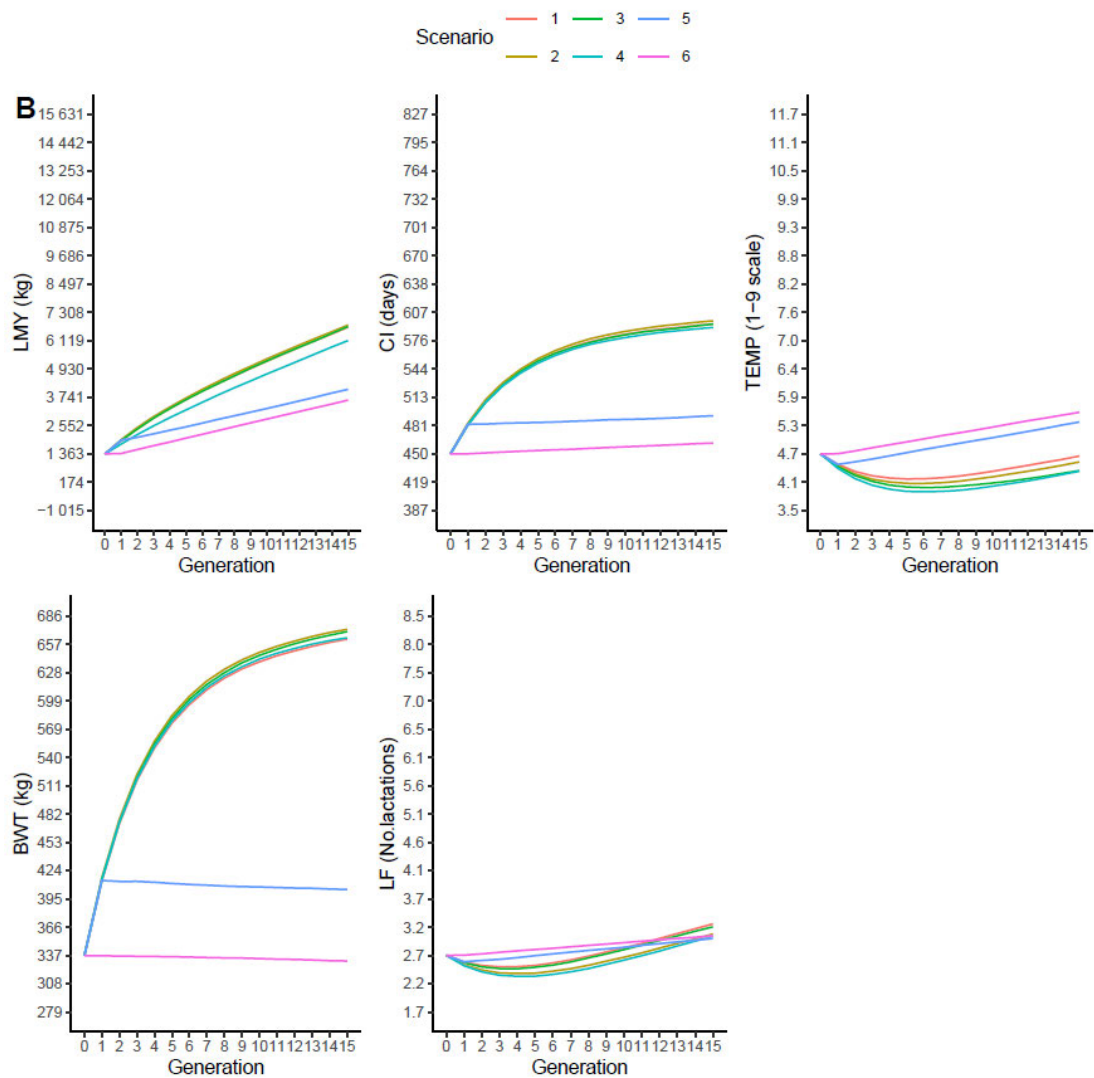
Figure 3 A, B and C Predicted genetic trends in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design in the highland agro-ecological zone. Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

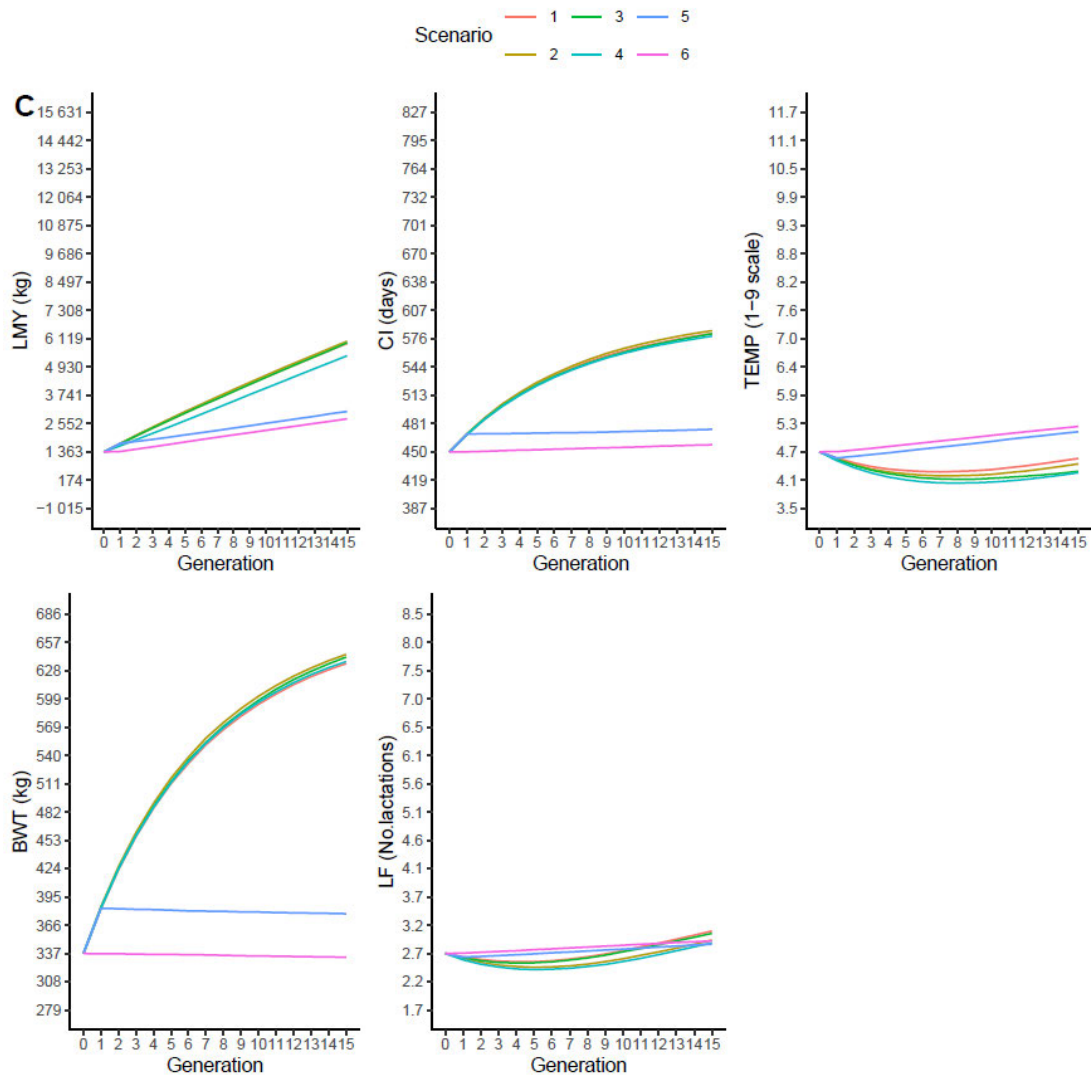


Appendix VI:

Figure 4 A, B and C Predicted genetic trends for individual animal traits in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design in the highland agro-ecological zone. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

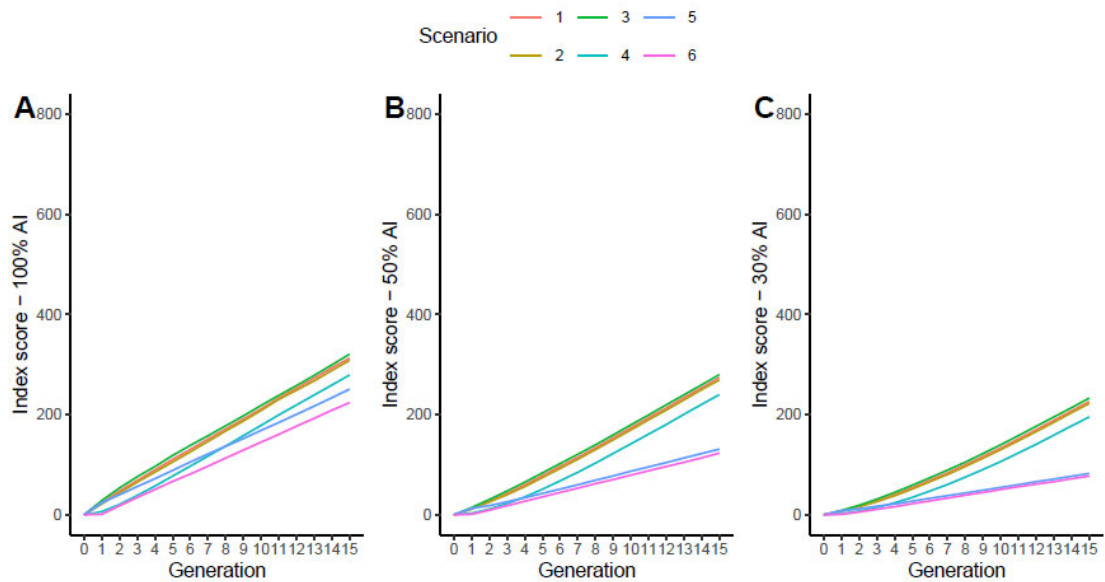






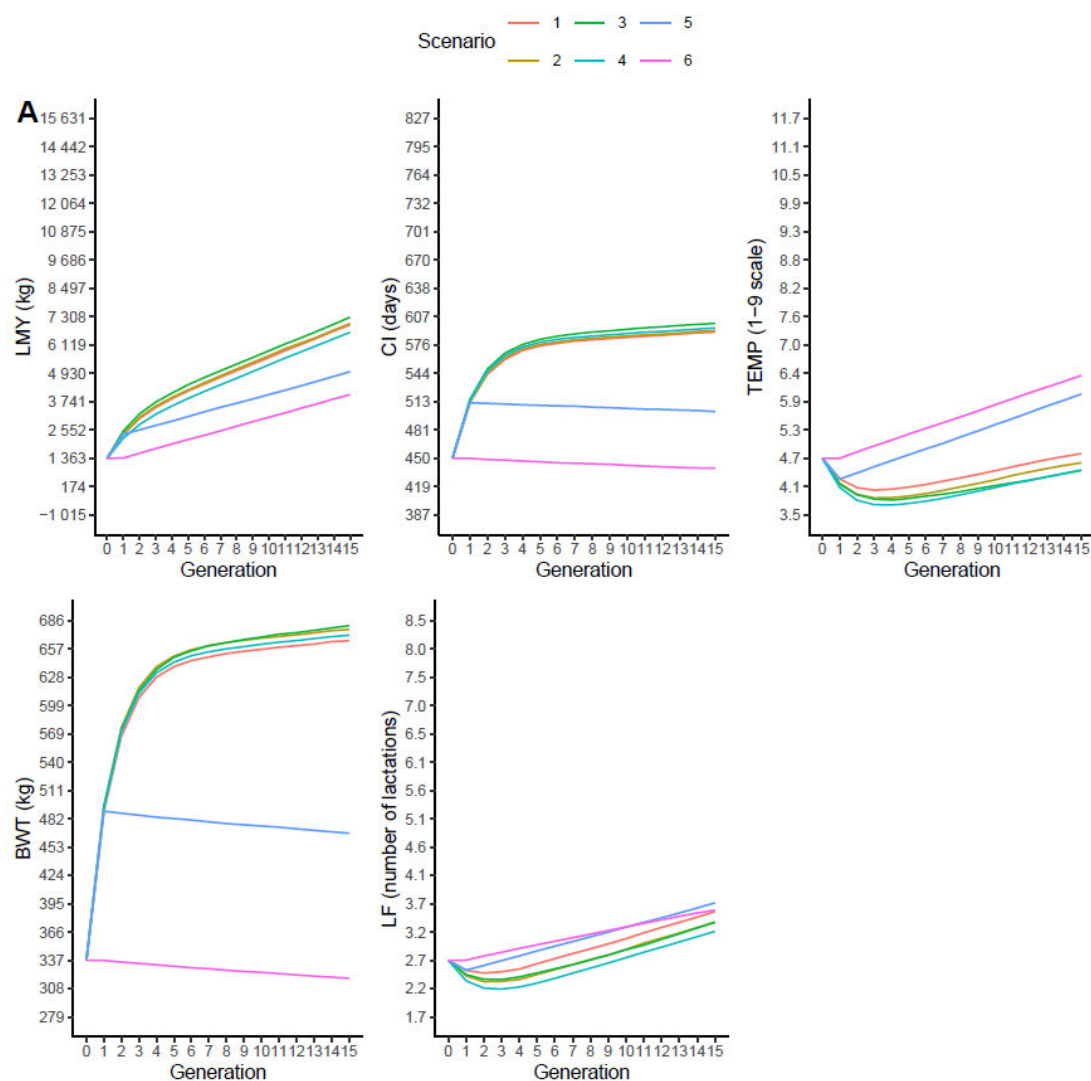
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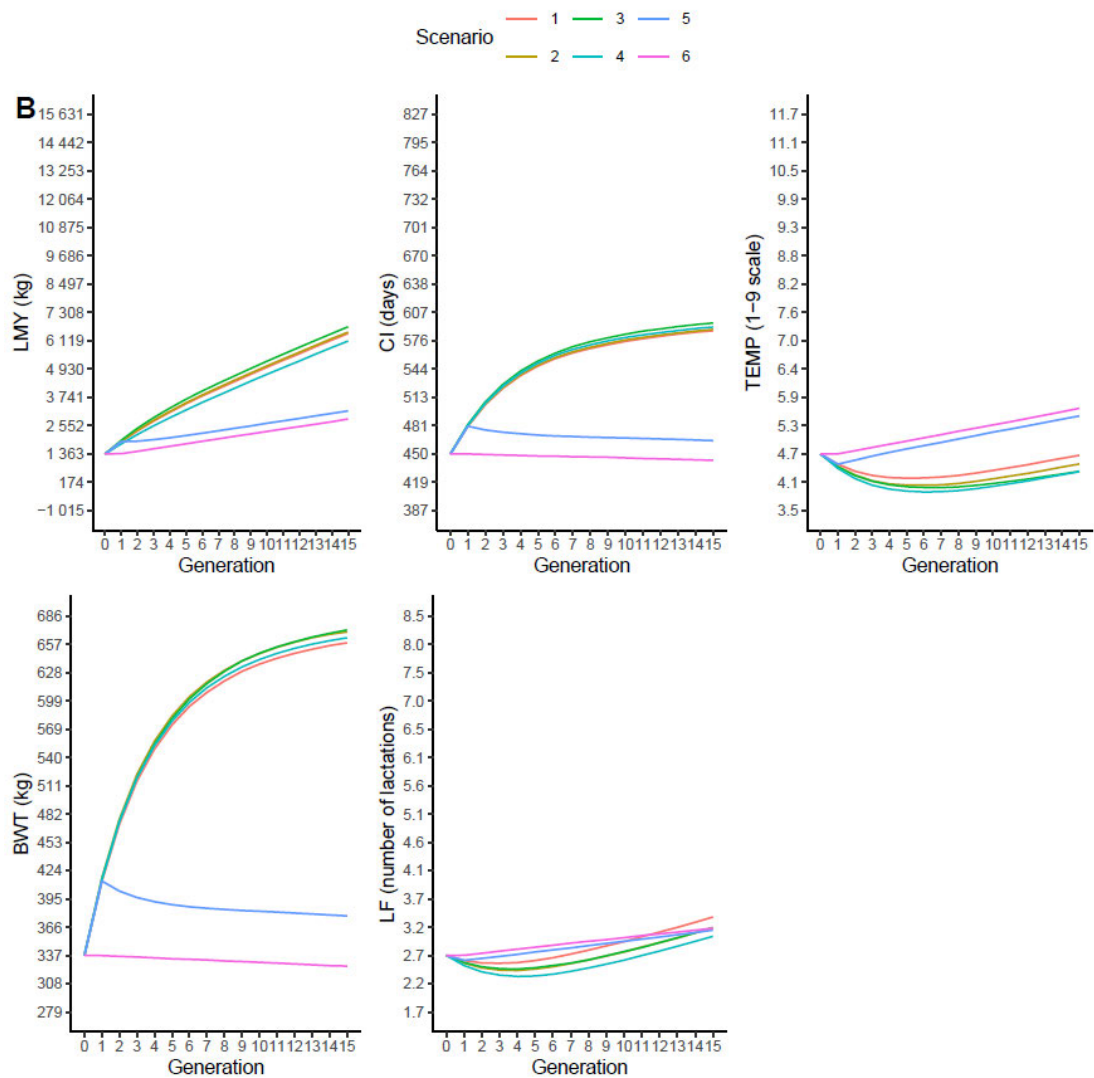
Figure 5 A, B and C Predicted genetic trends in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design in the coastal agro-ecological zone. Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

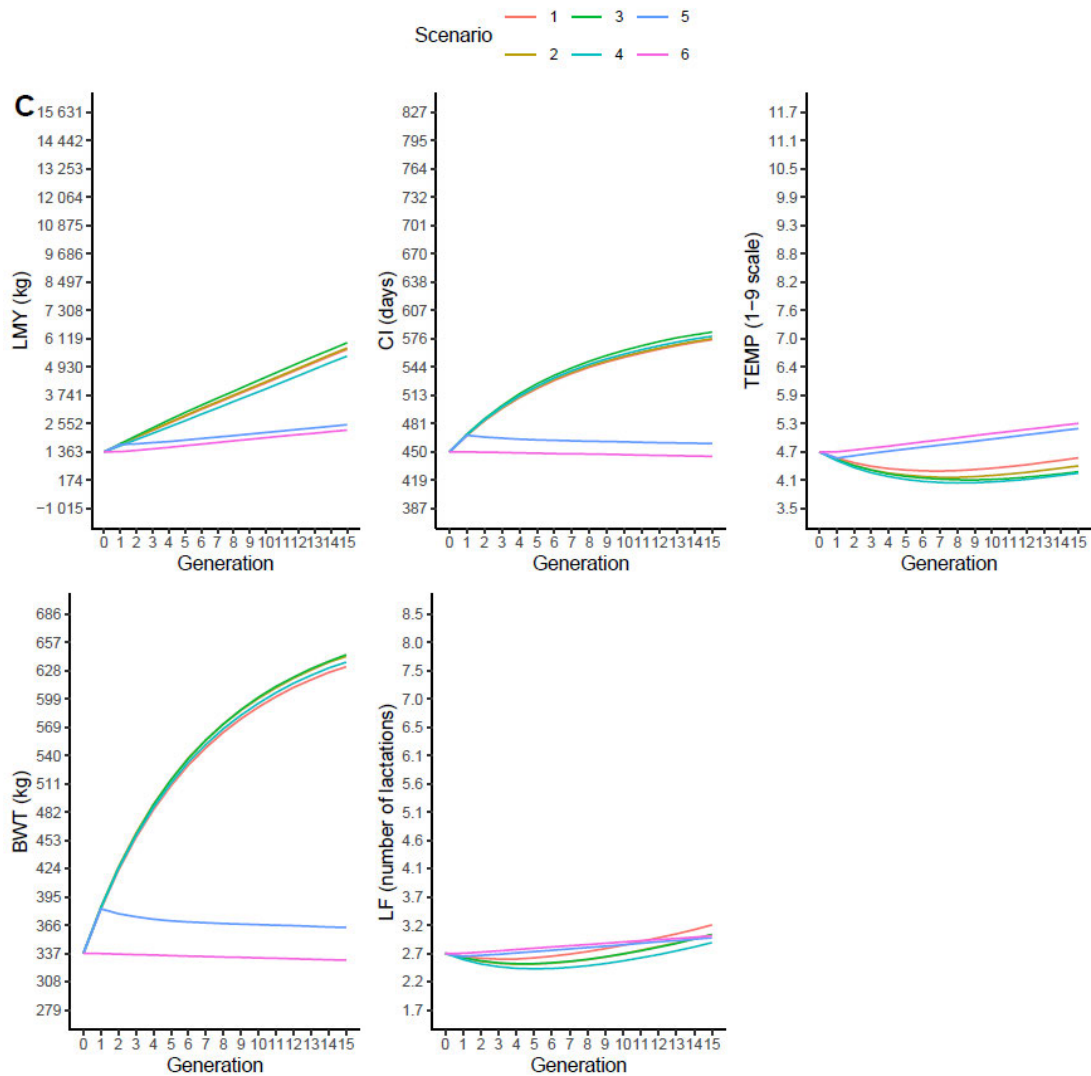


Appendix VI:

Figure 6 A, B and C Predicted genetic trends for individual animal traits in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when performance of exotic sires in Africa was assumed to be reduced by 25% compared to the base simulation design in the coastal agro-ecological zone. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

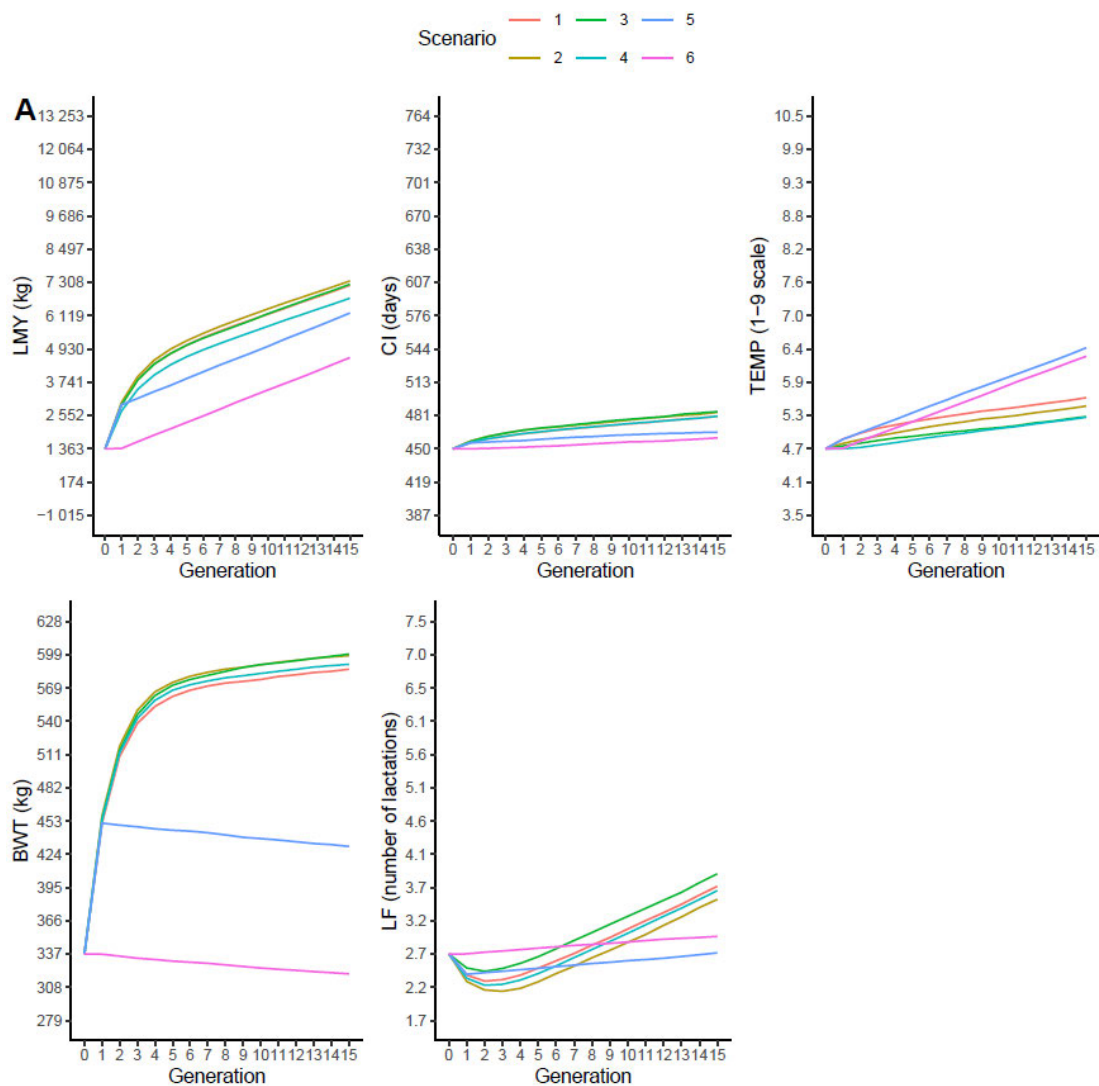


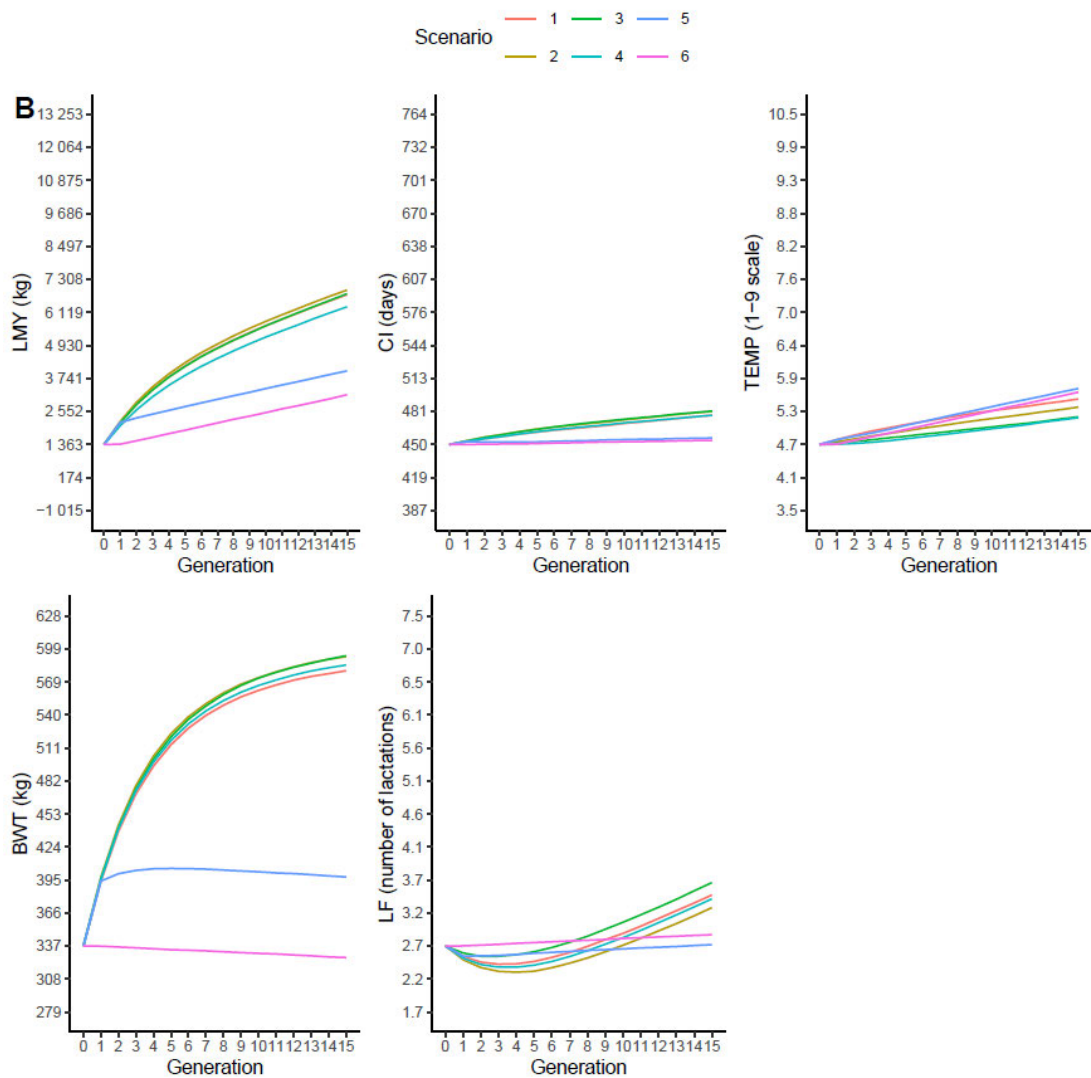


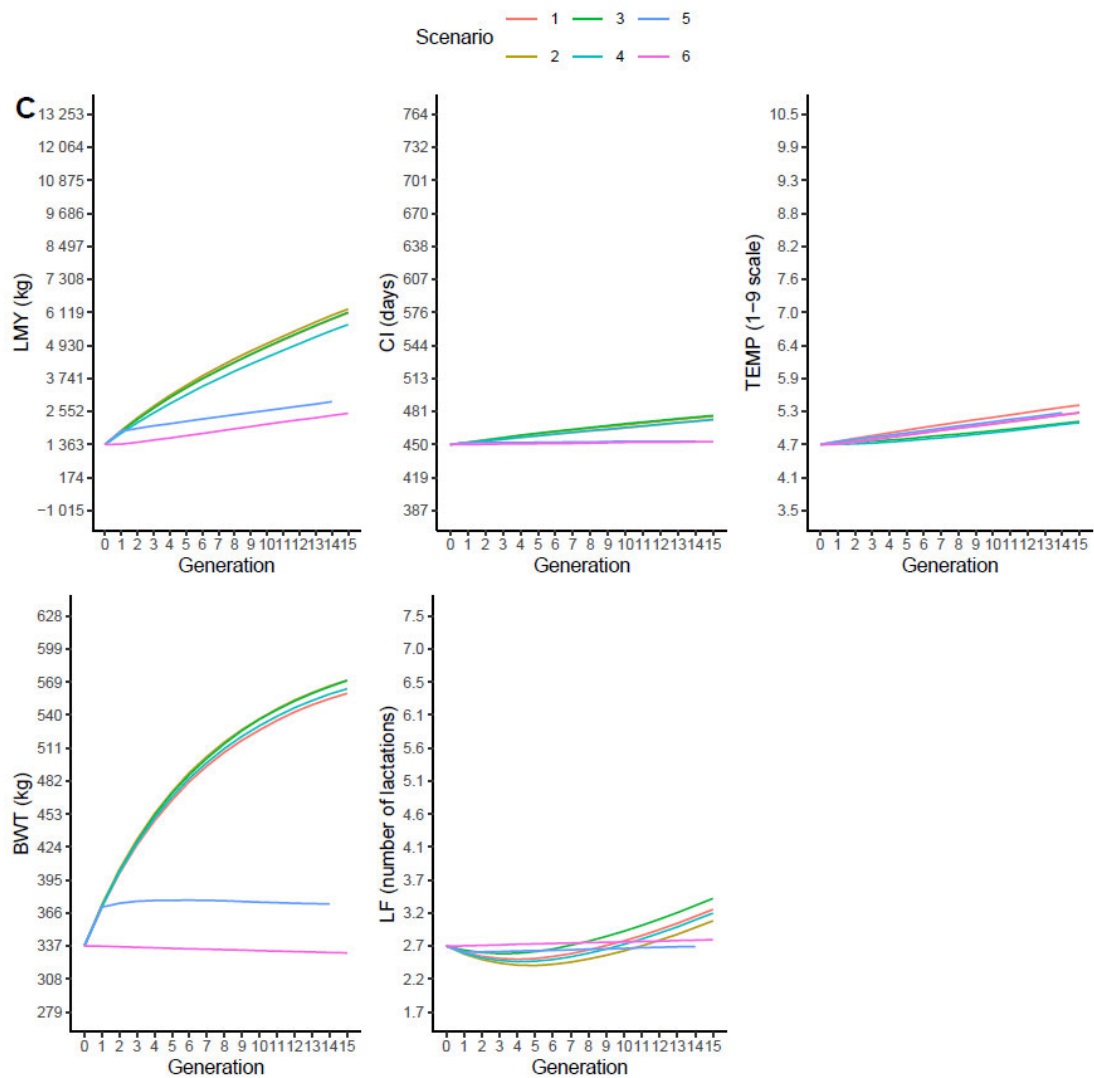


Appendix VII:

Figure 1 A, B and C Predicted genetic trends for individual animal traits in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when an antagonistic correlation between animal production and fitness (longevity) was assumed combined with reduced fitness of the exotic sires in Africa. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations). Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).

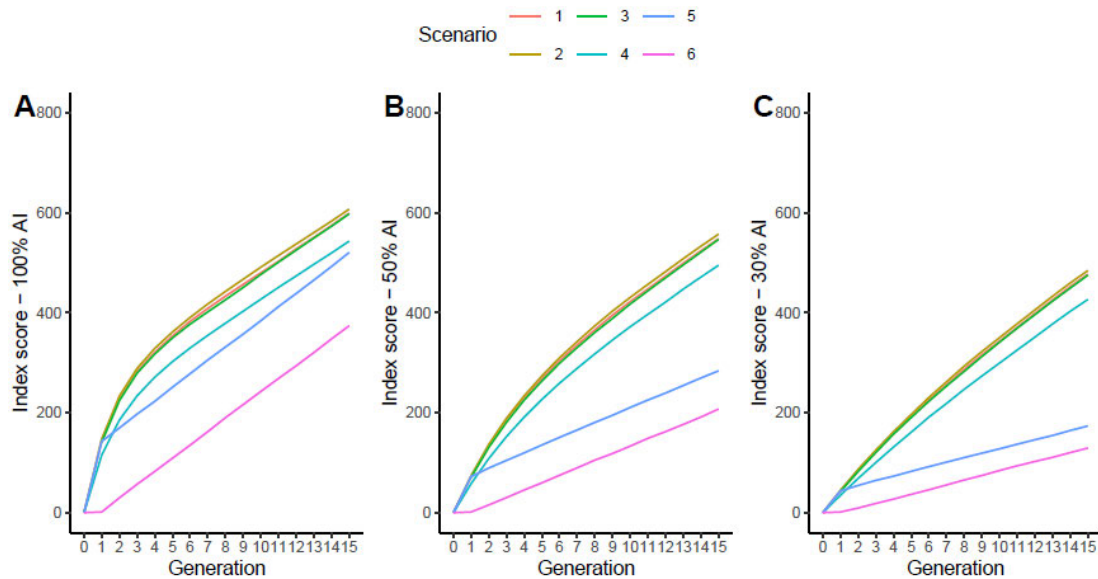






Appendix VII:

Figure 2 A, B and C Predicted genetic trends in African smallholder dairy systems at 100% (A), 50% (B) and 30% (C) AI schemes when an antagonistic correlation between animal production and fitness (longevity) was assumed combined with reduced fitness of the exotic sires in Africa. Scenarios 1-4 pertain to genetic selection of imported sires based on the Overall Farmer Index (including all five traits), a Reduced Farmer Index of LMY and CI, the Exotic Index and randomly, respectively (Strategy A); Scenario 5 pertains to sire selection based on the Overall Farmer Index within a new synthetic breed (Strategy B); Scenario 6 pertains to sire selection based on the Overall Farmer Index within the indigenous cattle population (Strategy C).



Appendix VII:

Table 1 Relative differences (%) in predicted genetic gain after 15 generations of selection based on the Overall Farmer Index between Scenarios 1 (Importation strategy), 5 (Synthetic breed strategy) and 6 (Indigenous breed improvement strategy); an antagonistic correlation between animal production and fitness (longevity) was assumed combined with reduced fitness of the exotic sires in Africa. LMY= milk yield (kg) in a 305 day lactation (kg); CI = calving interval (days); TEMP = temperament score (1-9 scale); BWT = mature live body weight (kg); LF = longevity (number of lactations).

AI-Strategy	Scenario comparison	Difference (%)					Overall Farmer Index
		LMY	CI	BWT	LF	TEMP	
100%	1vs5	13.75%	3.17%	26.43%	26.12%	-	13.11%
50%	1vs5	40.64%	4.54%	31.33%	21.00%	-3.33%	48.24%
30%	1vs5	51.05%	4.31%	33.25%	16.43%	1.7%3	63.60%
100%	1vs6	35.91%	4.25%	45.44%	19.67%	-	37.57%
50%	1vs6	53.32%	5.02%	43.58%	16.80%	-2.18%	62.16%
30%	1vs6	59.25%	4.47%	40.83%	13.58%	2.37%	72.89%

Chapter 6 General Discussion

The vision of dairy development for many countries in Sub-Saharan Africa (SSA) is to increase milk production to meet growing market demands. Dairy production has a significant role in improving the livelihood of farmers through income generation, food security and creation of employment. The aim of this thesis was to address breeding goals and breeding strategies in dairy cattle that may underpin future breeding programmes in smallholder dairy farming systems in SSA, using Tanzania as a case study. To achieve the aim the following specific objectives were set:

- 1) Perform a meta-analysis of relevant literature on animal performance traits in SSA and assess the effect of production systems and breed types.
- 2) Examine the level of genetic progress that has been achieved in centrally-based breeding programmes, using the Mpwapwa cattle breeding programme in Tanzania as a case study.
- 3) Identify farmer preferred-traits and assess their relative importance in smallholder dairy production systems.
- 4) Develop and evaluate dairy cattle breeding strategies, and determine genetic progress for the priority traits identified by farmers in different agro-ecological zones and production systems in SSA.

The novelty of this PhD thesis is manifested in the following: Firstly, a specifically-designed choice experiment survey was conducted to quantify the relative importance of individual animal traits that smallholder farmers want most. Farmer-priority traits for different agro-ecological zones and production systems have not been defined before in SSA smallholder dairy systems (Bebe et al. 2013, Duguma et al 2010). A clear insight into farmer preferences for animal traits in different agro-ecological zones and production systems was documented in Chapter 4 of the present thesis. Secondly, breeding strategies aiming to improve these farmer-priority traits were assessed. A breeding strategy based on gradual upgrade of the local cattle with systematic importation of sire semen selected on the Overall Farmer Index in Africa was found to maximise genetic progress. Additionally, there is novelty in the

examination of a strategy based on the formation of a new synthetic breed within the smallholder dairy farms by initial crossing of domestic stock with imported semen followed by selection of F1 sires to produce F2, then selection within F2 to produce F3 and so on. The newly established synthetic breed strategy might be possibly suitable for the sub-tropical coastal region. Lastly, the study presents for the first time farmer-driven breeding goals alongside predictions of the consequences of genetic selection of imported sires based on a range of different trait indices.

The study confirmed the hypothesis that there is a mismatch between what small holder dairy farmers truly want and the priorities previously set at central government level. Chapter 2 highlighted a list animal traits in SSA which reflects institutional and scientific interests from previous studies. A list of traits identified in Chapter 2 did not fully reflect the preferences of smallholder farmers identified in Chapter 4. There was mismatch on preference for animal traits considered by institutions and researchers to those preferred by farmers in Chapter 4. For example, animal temperament was the third most important trait for SSA dairy farmers after milk yield and fertility (Chapter 4) but was rarely considered in previous studies (Chapter 2). Government led breeding programme on the other hand have failed to deliver long term genetic progress for the breeding goals traits due to changes in policies and priorities. Lack of long-term genetic progress in government run breeding programmes was clearly demonstrated in Chapter 3. Results in Chapter 5 demonstrated the advantage of including farmer preferred traits (Chapter 4) in optimising the improvement of dairy cattle performance in smallholder dairy farms.

The present chapter provides a broader discussion of major findings from the previous chapters, highlighting key results and knowledge gaps that require more research. Discussion covers two main themes, 1) breeding goals for smallholder dairy farmers and, 2) genetic improvement strategies for smallholder dairy farmers in SSA. The present chapter also highlights the

implication and practical application of the research findings and future considerations.

6.1 Breeding goals for smallholder dairy farmers

In order to clearly define dairy cattle breeding goals for smallholder dairy farmers, the study was carried out in three distinct parts. Firstly, in Chapter 2 a critical review of the literature and meta-analysis of breeding goals was conducted. This part was based on the assumption that data availability and patterns of animal traits reported in multiple studies reflected institutional and scientific bias towards those traits. The hypothesis was that such traits did not fully reflect the preferences of smallholder farmers. Secondly, Chapter 3 examined the breeding goals, genetic parameters and genetic progress in a centralised breeding programme operated at a government research station. The hypothesis here was that centrally-driven top-down breeding programmes are predisposed to lack of long-term genetic progress. Lastly, Chapter 4 investigated the direct participation of smallholder dairy farmers in defining the breeding goal. The chapter aimed at bridging the gap between farmer's priorities and researcher's interests in designing bottom-up participatory dairy cattle breeding programmes for smallholder dairy farms. The research question was what should smallholder dairy farmers in Sub-Saharan Africa breed for to increase dairy productivity?

Interestingly, the scientific literature showed a bias towards fertility, milk volume production, disease resistance and welfare traits. Frequency of trait analysis from previous studies indicated that milk butterfat and protein content and animal temperament were rarely considered. Animal fertility and milk production were highly favoured traits of study aiming to maximise productivity and profitability of the smallholder dairy herds. Regardless of breed types, the performance of dairy cattle was higher in large-scale farms compared to smallholder dairy farms. Low performance of dairy cattle in smallholder dairy

farms was associated with the use of inferior bulls, inadequate nutrition as a result of small land areas, poor range management, and ineffective animal husbandry practices.

Smallholder dairy farmers often use improved animals from large-scale farms (both private and government or on-station research farms) as a source of breeding bulls for natural mating. Centralised breeding programmes have a great potential to be used as a source of breeding stock by smallholder dairy farmers. The next question was how much genetic progress has been achieved in centralised breeding programmes operated by research stations in SSA? To address this question, we used pooled data from Mpwapwa cattle, a synthetic dairy breed from Tanzania (Chapter 3). Analysis of 40 years of data on Mpwapwa cattle showed that the target for 305-day milk yield of 2,300 kg per lactation set in year 1958, has not yet been achieved. The 305-day lactation milk yield averaged 1,686 kg, which is 73% of the target. These results confirmed the hypothesis that centrally-driven top-down breeding programmes may be associated with lack of real long-term genetic progress for the breeding goals traits. Our findings appear to be well supported by Philipsson et al. (2011) who documented the reasons for failure of centrally based breeding programmes as lack of continuous technical and financial support. Despite the efforts made on breeding and multiplication of the Mpwapwa breed, the impact and anticipated results have not reached the majority of smallholder dairy farmers.

Most of the centralised breeding programmes have led to limited genetic improvement due to lack of interest and awareness because most of the breeding programmes are designed without farmer participation. There has been no long-term commitment of either researchers or farmers to the sustainability of these breeding programmes. Furthermore, centralised breeding programmes have failed because they are planned without considering the effects of the production environment in which cows are raised. As a result, farmers fear that improved dairy animals will not perform well in harsh environments. Major efforts should be directed towards formulation of

policies that underpin systematic breeding to increase productivity. In short, Chapter 3 showed that centralised breeding programmes have not made a significant contribution to the production and fertility traits of dairy cattle. The next step (Chapter 4) was to identify farmer driven breeding goals, which would be used for designing future breeding programmes.

Chapter 4 describes a choice experiment survey to identify farmer-preferred traits in different production systems. This chapter bridges the gap between farmers and researchers on perceptions regarding priority traits in designing breeding programmes. Using the choice experiment survey, which entailed direct participation of and interaction with smallholder farmers, trade-offs between important animal traits were identified and quantified. The most important dairy cow properties, in order of relative importance, were high milk yield, good fertility, easy temperament, feed utilisation efficiency and high disease resistance. In contrast to previous studies (Chapter 2) that rarely considered temperament traits, the choice experiment revealed that temperament was the third most important trait for SSA dairy farmers after milk yield and fertility. From the farmers' viewpoint, it was important to have a good interaction between a dairy cow and farmer. Furthermore, farmer preference traits differed between agro-ecological zones and production systems due to variation in climatic conditions, feed resources, and local genetic improvement infrastructures and services. These results suggest that breeding companies and policy makers need to take specific farmer preferred traits into consideration. Selection decisions and breeding strategies should be based on the identified farmer preferred traits in the specific agro-ecological zones and production systems.

6.2 Breeding strategies for smallholder dairy farmers

The government of Tanzania has been responsible for providing all necessary investment for dairy cattle improvement programmes. Research

and development work has been carried out to increase productivity of dairy cattle through various genetic improvement initiatives (Kurwijila & Boki, 2003). The government through the lead Ministry for livestock sector, livestock research institutions, government livestock multiplication farms /units and the National Artificial Insemination Centre have promoted breeding schemes that involve upgrading indigenous breeds with randomly selected and imported sires from temperate countries. These sires were meant to be crossed with locally raised cows. However, because of the lack of clear crossbreeding and selection strategies, upgrading to higher grade exotics has resulted in substantial economic losses due to high mortality rates of crossbred offsprings (Shoo et al. 1992; Swai et al. 2010). Possible new breeding strategies and selection scenarios that could be adopted for genetic improvement of dairy cattle in Tanzania are discussed next.

6.2.1 Use of exotic sires for upgrading indigenous cattle breeds

Genetic improvement strategies based on systematic importation of selected exotic sire semen were investigated in Chapter 5. Genetic selection of imported sires was based on the Overall Farmer Index including all five farmer-preferred traits, a Reduced Farmer Index including milk yield and fertility, an Exotic Index used for sire selection in the exporting country, and random selection. In this strategy, sire semen were selected in each generation from the country of origin of exotic sires based on the above indices. Results were evaluated based on progress achieved in the farmer-preferred traits individually and collectively.

Genetic selection based on the Overall Farmer Index led to higher genetic progress compared to the other scenarios. This selection criterion is expected to be most useful in semi-temperate highland areas, where the climate is favourable for upgrades compared to the predominantly tropical climate in costal zones. The Reduced Farmer Index was the second best selection criterion and may be more immediately applicable due to data

availability. Systematic importation of exotic sires for upgrading with indigenous breeds is proposed as a feasible approach for sustainable dairy production in smallholder dairy systems. This approach takes advantage of genetic selection and breed complementarity, and could be adopted as the fastest means of increasing dairy productivity.

The phenotypic advantage of crossbreeding was seen in F1, due to maximum heterosis. Performance in subsequent generations was below expectations due to recombination loss (Rutledge 2001). However, the performance stabilised due to selection as the upgrade of the population progressed.

6.2.2 Creation of a new synthetic breed

Development of new tropically adapted breeds has been proposed as a way to promote sustainable dairy production in the tropics (McDowell, 1985). Formation of synthetic breed needs two or more parental breeds as foundation stock, which are crossed to produce F1. Formation of F2 involves a selection of F1 sires to mate with F1 females to produce F2 and the mating process is repeated in succeeding generations (McDowell, 1985). Results from previous studies show that attempts to establish synthetic breeds are seriously challenged by small populations of animals kept on-station, inadequate funding and lack of clear evaluation and dissemination strategies. Besides, synthetic breeds have been previously developed without considering farmers' priorities (Chawala et al. 2017, McDowell, 1985).

The present study assessed a novel systematic crossbreeding strategy for creating a synthetic breed in smallholder dairy farms using crossbred sires selected within the smallholder herds. This strategy is different from the previous strategies where heifers bred from on-station and government research farms were distributed to farmers instead of being used as replacement to the base population. Unlike previous approaches, this strategy allows for the creation of synthetic breeds within smallholder farms through

continuous crossing of females with improved crossbred sires selected within a population. Breeding bulls for each generation will be selected based on their performance and will be submitted to NAIC for semen collection. This strategy is presented as a feasible approach in tropical and lowland coastal zones where productive environment is less favourable for upgrades. It is expected that forming new synthetic breed might contribute to enhancing the biodiversity in the region due to different proportions of exotic genes maintained in a population depending on levels of AI penetration.

6.2.3 Genetic selection within indigenous breeds

The conservation of African indigenous cattle breeds is an important consideration when designing a national breeding programme. According to Galukande et al. (2013), conservation of indigenous breeds should become part of new breeding programmes in a particular production system. African *Bos indicus* breeds have low genetic potential for milk yield. However, these breeds have better genes for disease resistance, and heat and drought tolerance, and also offer unique genetic features for the utilisation of low quality forages. In addition, the indigenous breeds are diverse and have a significant contribution to cultural heritage and identity (Mwai et al. 2015).

The present study investigated a breeding strategy based on genetic selection within the indigenous population for farmer-preferred traits, considering phenotypic and genetic parameters of the Boran and Sahiwal breeds as foundation stock for selection (Haile-Mariam and Kassa-Mersha 1994; Ilatsia et al. 2007; Musingi et al. 2018; Wasike et al. 2009). These two breeds were chosen because they are known to have more milk production compared to other indigenous breeds in East Africa. Recent studies in Kenya by Lukuyu et al. (2019) reported that Sahiwal and Boran were the mostly preferred breeds compared to other East African Zebu in smallholder farming systems. Results showed that genetic selection within the indigenous population will lead to lower progress in the farmer-preferred traits compared to the other two strategies. This is due to the low productivity potential of these

breeds combined with the fact that increasing milk yield is the top priority of smallholder dairy farmers. Nevertheless, the strategy showed some promise regarding improvement of animal longevity and fertility. This calls for breeding companies and smallholder dairy farmers to exploit the beneficial traits of indigenous cattle when designing breeding programme in smallholder systems. For example, a portion of indigenous cattle could be used as a vital source of germplasm for crossbreeding with exotic sires from exporting countries to improve dairy productivity.

The strategy discussed here (indigenous cattle selection) was found not to be competitive compared to the other two breeding strategies of the study. In fact, the most successful strategy at improving the farmer-preferred traits, the systematic importation and upgrade strategy, could lead to a gradual replacement of the indigenous cattle. Although this may make good market sense, protection of the local breeds is warranted for diversity, heritage and traditional identity. In-situ conservation could be implemented with formal selection programmes using the Overall Farmer Index to improve productivity and to maintain genetic diversity within the indigenous population. Ex-situ conservation may involve strategies of preservation of somatic cells, semen and embryos.

6.3 Implication of results

On the issue of breeding goals identified by smallholder farmers, breeding companies and government policy makers need to decide how to promote “dairy as a pathway out of poverty” and “dairy as pathway into food security”. “Dairy as pathway out poverty” is farmer driven, while “Dairy as a pathway into food security” is consumer driven focusing on the energy of the product and beneficial nutrients such as milk butterfat, protein, vitamins and minerals. The present study investigated farmer-driven breeding goals. Based

on the findings in Chapter 4, the breeding goal for smallholder dairy farmers can be defined in a broader context as,

To breed and maintain docile cows with high fertility, whose offspring would produce high volumes of milk and survive in low and medium input production environments.

The identified farmer-preferred breeding goals are in line with the national policy documents such as Tanzania Livestock Master Plan (Michael et al., 2018) and National Livestock Research Agenda 2020 - 2025 (URT 2019), which highlight the importance of the dairy sector in poverty reduction and improved food security. The policy documents also stress the need to increase dairy cow productivity through genetic improvement, health, nutrition and increase in number of improved dairy cattle.

Participation of consumers in defining breeding goals has not been considered here but may be critical to address in future studies. Consumers may focus on other milk characteristics that have not been identified as priority by the smallholder farmers, yet. Combining farmer and consumer needs in developing breeding goals is highly recommended for the future of the smallholder dairy farm sector. It seems reasonable to assume that traits reflecting consumer needs be added to the Overall Farmer Index presented here, following future analyses of appropriate weightings in comparison with the farmer-preferred traits.

An efficient and a fully operational breeding strategy will need both smallholder dairy farmers and government institutions buy-in. It is expected that farmers will be willing to pay for genetically improved sire semen depending on the adopted breeding strategy. Furthermore, financial and technical support will be needed from government, private sector and non-governmental organisations. The breeding strategy applied should also take into consideration the need for a well-designed and cost effective animal recording system. This should be accompanied by a reliable and efficient AI service and agreed way of exchanging germplasm to minimise inbreeding

levels within herds or villages. The breeding strategy will require the establishment of a national genetic evaluation system and a standing committee that will meet regularly, for example once or twice per year, to review the breeding goal and lay out and monitor the operational practices. For long-term sustainability, a policy and a business plan must be in place to ensure both technical and financial self-sufficiency of the breeding programme. Breeding companies will need to provide guidance on appropriate sires for different agro-ecological zones and production systems. Finally, a breeding strategy will require the other complementary services discussed in Chapter 2, such as access to a reliable market for the final product, affordable animal health services, feed resources and continuous technical back up through extension services.

To a large extent, genetic progress for the farmer-preferred traits in the breeding goals will depend on the size of population participating in the breeding programme and the adopted breeding strategy. AI offers a great advantage of using genetically improved semen to increase productivity in smallholder farms. This thesis highlights the need for appropriate policies and strategies that will enhance the adoption of AI by a large proportion of smallholder farmers to improve dairy productivity.

All three breeding strategies described in detail in Chapter 5 could be adopted in Tanzania, depending on level of intensification and production environments. Three possible dairy production systems are expected to emerge based on the biological potential of the offspring resulting from the proposed breeding programmes: i) *Intensive high-grade exotic dairy production system*. The evolution of this system will involve upgrading indigenous cattle with exotic sires selected based on the importation strategy. This is expected to dominate in intensive highland systems taking advantage of favourable agro-ecology for exotic dairy cattle. ii) *Synthetic or composite breed dairy production systems*. This system is expected emerge through *inter se* mating of F1 animals that resulted from an initial crossing between indigenous cows and exotic sires. This system could be suitable for extensive

smallholder farming systems in the sub-humid eastern coast and lowland agro-ecological zones where high-grade exotics can hardly survive. iii) *Improved zebu dairy production system*. The system can take the advantage of pure-breeding of indigenous cattle using selected domestic sires. Communities who own indigenous cattle, such as Maasai, can adopt this system. The realised milk yield is expected to gradually increase especially in arid and semi-arid areas where these communities are mostly found.

Genetic improvement strategies have to go parallel with improvement in nutrition and management practices. In order to cope with seasonal variation in feed quantity and quality the current study emphasised on selection for low mature live weight. Development of synthetic breeds and systematic upgrading of indigenous cattle with selected exotic sires is expected to produce animals that are compatible with the existing resources. Dairy cattle born in Africa will have lower mature live weight compared to their counterparts in the exporting country due to selection. Selection for low mature live weight ensures reasonable returns for money spend in feeds. Breeding for longevity is another benefit that adds to the returns to money spend for disease and parasite control. It is expected that milk production based on locally adapted animals will contribute to the poverty alleviation and improving food security among the rural poor population.

6.4 Future considerations

Results from the present study show that the relative emphasis on farmer-preferred traits in the breeding goals differs across agro-ecological zones and production systems. Future research should place a monetary value on each trait in each agro-ecological zone and production system. To account for farmer and consumer needs, future breeding goals should include consumer preferences and attitudes towards dairy products. Recent studies have shown that, consumer intention to pay for food safety and quality is

increasing in Tanzania due to increased income per capita (Alphonse and Alfnes, 2012). There is a need to explore how consumers value specific milk attributes linked to food safety and nutrition. A detailed bio-economic modelling study is required to assess the relative importance of traits identified by farmers, consumers and processors. This will require data on milk production, cow replacement costs and prices for different dairy products. Genetic parameters for resilience and fitness traits, and milk quality attributes are scarce in Africa. Future work should consider generating data and parameters for these traits for inclusion in the design and implementation of breeding programmes. Capacity strengthening for personnel who will be responsible for designing and implementation of breeding programmes need to be emphasised. The success of breeding strategies will depend on short and long term investment in the human capacity to run the breeding programmes. Further studies should focus on including environmental traits of global concern such as greenhouse gases (GHG) in selection indices. Environmental impact traits were not included in the breeding goal for smallholder dairy farmers but it is possible to include in the selection index in order to select animals with less GHG emissions. Finally, recent development in genomic technology provides an opportunity for the selection of the best bulls in smallholder dairy production systems. Genomic selection should be considered in the selection for traits with low heritability, traits with recording difficulties (traits recorded in late life, disease traits), and environmental sensitive traits (eg. methane production), behavioural traits (e.g temperament), nutritional traits (milk composition) and other genomic information that are relevant for advancing dairy productivity in SSA countries.

6.5 Concluding statements

The results presented in this thesis clearly demonstrate that bottom-up (farmer-led) breeding goals and strategies are feasible in smallholder dairy systems in SSA. Breeding goal traits and selection indices were identified and

documented. Amongst the breeding strategies investigated, the gradual importation breeding strategy led to an overall higher genetic progress compared to other strategies, due to the high relative emphasis placed on milk yield by the smallholder farmers.

Overall, the thesis has demonstrated that integration of farmer-led breeding goals in designing breeding programmes will increase dairy productivity. It is also expected that farmer participation in the implementation of breeding programmes will increase the long-term sustainability of the established breeding programmes. Benefits accrued by farmers through increased milk yield, good fertility, docility of cows, low feed requirements and resistance to diseases will strengthen the breeding programmes and motivate more farmers to participate in genetic improvement initiatives. Lastly, results from this thesis can be used by farmers, government and other development partners in planning sustainable breeding programmes in Tanzania and more widely in Sub-Saharan Africa.

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